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AN ATTEMPT TO CORRELATE NORMAL VORTICITIES WITH TOTAL PRESSURE DISTORTION PATTERNS AT THE ENTRANCE TO A GAS TURBINE ENGINE

PERFORMANCE/STABILITY DIVISION
DIRECTORATE OF ENGINEERING AND TEST
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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

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An attempt is made to predict the worst-case pressure distortion produced by a distortion screen at the entrance to a gas turbine engine using only steady-state total pressure measurements. The vector sum of radial and circumferential vorticity, called normal vorticity, is compared to both the difference between steady-state and worst-case distortion patterns, and the standard deviation of the high response pressure measurements, called "turbulence." Average values of "turbulence" and vorticity are found to be unrelated to the increase in next pg

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Abstract

An attempt is made to predict the worst-case pressure distortion produced by a distortion screen at the entrance to a gas turbine engine using only steady-state total pressure measurements. The vector sum of radial and circumferential vorticity, called normal vorticity, is compared to both the difference between steady-state and worst-case distortion patterns, and the standard deviation of the high response pressure measurements, called "turbulence." Average values of "turbulence" and vorticity are found to be unrelated to the increase in distortion between steady-state and worst-case pressure measurements. Probe-by-probe analysis of the data indicates that a correlation may exist between vorticity and the distortion increase. Although a final prediction technique is not developed, an improved test program and refined data analysis techniques are outlined.

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Chapter I Introduction

Background

Most turbine engines for modern aircraft are designed to operate with the air entering the engine in a uniform velocity profile. A few engines are designed to have the inlet velocity lower at the tip of the compressor than at the hub to optimize the aircraft system performance. In both cases, engine inlet distortion is defined as any perturbation in the compressor inlet velocity profile from the desired velocity profile. If the inlet distortion is too great, the compressor will stall.

Due to the difficulty of measuring the velocity profile of the air entering a turbine engine, indirect measurements must be taken. Current techniques for approximating the inlet velocity variation involve the use of an array of total pressure probes at a turbine engine inlet. Engine inlet velocities are on the order of 0.5 Mach number and incompressible fluid flow is assumed at the measurement plane. The static pressure is nearly uniform if the instrumentation plane is placed far enough in front of the compressor face and its flow redistributions. Therefore, the variation of the total pressure of the air entering a turbine engine is a reasonable approximation of the variation of the inlet velocity. The total pressure probes are usually designed so that good total pressure recovery can be obtained for engine inlet air velocity varying up to 30° from the axial direction.

Current Practice

The development of the F-111 aircraft system was plagued

with engine/inlet aerodynamic compatibility problems. Most of the problems were caused by the aircraft inlet producing more flow distortion than the engine could tolerate. Since the F-111 system development, the U.S. Air Force has directed that during the development of new aircraft systems, especially supersonic aircraft systems, the inlet pressure distortion be measured with high response instrumentation both during scale model tests and flight tests, and that turbine engine qualification tests demonstrate the engine capability to accept a reasonable amount of inlet flow distortion. The turbine engine is qualified in an altitude test cell under well controlled and accurately measured conditions. The aircraft inlet flow distortion is presently simulated by placing a distortion screen in front of the engine. A distortion screen consists of a heavy metal mesh of low blockage to which are attached one or more screens of higher blockage. The screen pattern is such that an engine inlet total pressure distortion pattern is produced which nearly duplicates a specified inlet distortion pattern. Unfortunately, because the pressure gradients produced by the distortion screen are a function of the airflow through the screen, the distortion screen will produce the desired distortion pattern at only one design airflow condition. Reference 5 is an excellent description of a good technique for the design of engine inlet distortion screens.

Using Figure 2 as an example, the distortion screen has an inner diameter of approximately 4 inches and an outer diameter of approximately 35 inches. The basic grid is spread across the

entire face of the screen and consists of 0.125 inch diameter wire in a square pattern of one wire per inch. The remaining screen mesh consists of 0.063 inch diameter wire in a square screen pattern with from two to nine wires per inch. These secondary screens are cut to approximate the isobars of the design distortion pattern and are not allowed to overlap each other. Although the secondary screens are safety-wired to the basic grid during screen development, they are brazed to one another and the basic grid after the design has been finalized.

Problem Definition

As would be expected, the flow downstream of the distortion screen is quite turbulent. The turbulence causes the pressure to oscillate about the average, or steady-state, pressure reading. The steady-state total pressure distortion will be less severe than the actual total pressure distortion that would appear transiently at the engine compressor face. Therefore, high response pressure instrumentation is required to accurately determine the flow distortion entering a turbine engine. The data obtained with the high-response pressure probes are referred to as dynamic data. However, high-response (approximately 800 Hz) pressure transducers, the associated hardware, and the increased data reduction requirements are very costly. Because of the increased costs of high response pressure distortion measurement, many Air Force systems are forced to use only steady-state pressure measurements to determine inlet screen distortion. A technique is needed to predict the worst-case dynamic distortion using

only steady-state pressure measurements. This paper summarizes an attempt to develop such a technique.

Reference 6 states that during the FB-111 flight test program, high pressure turbulence levels were associated with large gradients in the inlet total-pressure distortion pattern. This trend was judged to be indicative of regions that were reacting to large shear forces. It would therefore appear that a system for the measurement of the magnitude of pressure gradients would serve to approximate the amount of tubulence. If the amount of turbulence could be predicted, a factor might be devised which would serve to modify a distortion pattern measured with only steady-state pressure instrumentation. Should it succeed, then the steady-state pressure measurements alone would suffice to estimate the worst-case dynamic distortion pattern generated by a distortion screen.

Scope of Present Study

References 1 and 2 descibe a system for calculating pressure gradients at the entrance to a turbine engine. A summation of these references is contained in a later chapter of this study. The pressure gradients are examined through the use of cylindrical coordinates. Equations are developed to calculate terms corresponding to the pressure gradients in the axial, radial and circumferential directions. The radial and circumferential pressure gradients are of primary importance to this study. Suffice it to say that the formulae for the radial and circumferential pressure gradients involve the axial velocity of the air entering

the compressor, the total pressure at the engine face, and the radial and circumferential pressure gradients at the compressor face. References 1 and 2 choose to call the resultant terms absolute vorticity. Hereafter the term vorticity will apply to the above definition. As the sum of radial and circumferential vorticity should be the best parameter to predict turbulence, the total vorticity was obtained by vector addition of the radial and circumferential vorticity.

High quality data were obtained from a distortion screen calibration effort and exposed to the hypothesis described above. Distortion was measured in terms of (maximum total pressure - minimum total pressure) / average total pressure at the engine face. This term is referred to as $\Delta p/p$. The dynamic pressure data were digitized so that the pressure readings from all 48 pressure probes were recorded simultaneously, with 0.00096 seconds between each data scan. Computer programs were used to scan 512 data scans to determine the worst-case pressure distortion levels for each data point. A computer program was devised to calculate and plot the total vorticity from the steady-state pressure measurements. The dynamic data were scanned to determine regions of the distortion pattern where the dynamic data varied most from the steady state values. For this study "turbulence" was defined as the standard deviation of the dynamic total pressure measurements from the steady-state total pressure measurements. An attempt was then made to correlate the "turbulence" levels with the difference between the steady-state and dynamic pressure

distiortion patterns. A correlation was then attempted between the total vorticity and the "turbulence" levels. The final step was to attempt a direct correlation between the total vorticity and the difference between the dynamic and steady-state distortion patterns. The final objective was to develop an empirical technique to predict the worst-case total pressure distortion produced by an inlet distortion screen. The technique was to use only steady-state total pressure measurements and produce worst-case distortion predictions accurate enough to withstand the critical scrutiny of the U.S. Air Force and its engine manufacturers.

Chapter II Source of Data

Data Program

The data for this study were obtained from February 1 through April 6, 1973, by ARO, Inc., contract operator of the Arnold Engineering Development Center (AEDC), Arnold Air Force Station, Tennessee. The tests were performed under ARO project number RA 308 under Air Force Systems Command (AFSC) Element 64209F. (The tests were directed and funded by the F-15 Systems Program Office at Wright-Patterson Air Force Base, Ohio.) A copy of the letter authorizing the use of these data is contained in Appendix B.

Distortion Screens

The five distortion screens used in qualification testing of the F100-PW-100 turbofan engine were investigated. The data from the calibration of one distortion screen were discarded due to the low total pressures, and associated measurement inaccuracies, resulting from the simulated 58,600 ft. altitude / 0.9 Mach number (58.6K/0.9) flight condition of the test. Figures 2 through 5 are schematics which present the grid size and percent blockage of the remaining four screens. Each screen was required to produce a specified distortion factor at a corrected airflow, altitude and Mach number. Figure 1 is a description of the goal distortion patterns for the design of the four screens used in the test program. The objective of the screen design program was to duplicate the normalized pressure readings of these goal patterns to within 2% root-mean-squared error on a probe-by-probe basis. The

screens were found to conform to these criteria. Although data were generated at several airflow conditions for each of the four screens, the only data used for each screen were that generated at the design airflow.

Facility

The data were generated at the AEDC Engine Test Facility's J-1 test cell, which has an inner diameter of approximately 16 feet. The test hardware for this program consisted of the Pratt & Whitney Aircraft Company F-15 Aircraft Full-Scale Inlet Simulator and an engine simulator (cold pipe). A detailed schematic of the installation is shown in Figures 6 and 7. In Figure 6 air of a desired pressure and temperature entered the test cell from the left, as depicted by the arrow. The air first passed through a metal honeycomb and a screen which served as flow straighteners. Next the air passed through the venturies which served to measure the total cell airflow. All bypass and leakage air was subtracted from the total flow to obtain the airflow through the cold pipe. The flow exiting the venturies was broken up by air baffles before entering a low velocity plenum and conic screen. Next the air entered a transition duct to the F-15 inlet simulator. Air exited the inlet simulator through either the cold pipe engine simulator or the lower ramp bypass. Test cell pressure was maintained by facility exhausters which reduced cell pressure through the exhaust diffuser.

The F-15 inlet simulator, as sketched in Figure 7, was designed to simulate the flow at the engine face produced by the

actual F-15 aircraft inlet. The F-15 inlet uses three external ramps to create three oblique shocks prior to the normal shock during supersonic flight. The inlet simulator simulated only the end of the second ramp; the rest of the inlet to the cold pipe was an exact duplicate if the aircraft inlet. Through this configuration only the final oblique shock and the normal shock were simulated during supersonic flight. During simulation of actual inlet operation the lower ramp bypass and lower ramp position were regulated to obtain the proper Mach numbers and flow angles that would occur during flight. For this test program, the inlet simulator was configured to obtain the most uniform flow in the cold pipe inlet. A thorough description of the inlet simulator and its operation is contained in Reference 3.

The J-1 test cell, with the inlet simulator installed, was chosen for the screen calibration because dynamic data recording and processing systems were readily available to make the required time-dependent measurements and because no F-100 engine was available at that particular time period for testing in the J-1 test cell. For this test program all bleed and bypass lines were blanked off with the exception of the 36 inch lower ramp bypass line. Also, the fourth ramp bypass line was removed and the bypass valve closed, but with no blank off plate installed, and the primary air measuring venturis 3, 6, and 7 were blanked off. Unique test hardware for this program consisted of the following:

1. The environmental control system section used during the F100-PW-100 engine tests was replaced by a straight pipe

which connected the end of the sunsonic duct to the instrumentation at the simulated engine face. A radial grid assembly was installed inside of this duct to which the distortion screens were attached. The screen face was 28.7 inches forward of the cold pipe flange.

2. To reduce the distortion of the flow field at the entry plane of the distortion screens, a flow straightening grid was installed approximately 58 inches upstream of the subsonic duct exit. Figure 8 is a schematic of the subsonic duct and shows the position of the flow straightening grid in the duct. This flow straightening grid was retained in the duct by bars which passed through the subsonic duct structure. Upon completion of the test program, the straightening grid and the support bars were removed and leak-tight plugs installed in the subsonic duct.

3. The cold pipe exit was fitted with a conic nozzle to effect airflow control. When required by test conditions, the nozzle area was changed by replacing the conic nozzle. Figure 9 is a schematic of the conic nozzle installation and also documents the areas and the area ratios of the conic nozzles used during this test program.

Test Conditions

The test conditions for each screen are as described in Table 1.

Test / Data Point	Screen	Alt./Mach	P_2 psia	T_2 °R	P_{s2} psia	Corrected Airflow
HA-08/10	4-5F	65.5K/2.2	6.90	769	6.21	147.1 (lb/sec)
HA-16/10	5-1F	68K/2.5	9.96	800	9.10	128.1
HA-17/12	1-7F	30K/0.9	6.61	481	4.77	229.3
HA-18/24	3-5F	64K/1.6	3.30	590	2.72	200.7

Table 1

P_2 is defined as the average total pressure at the engine inlet, P_{s2} is the average static pressure at the engine inlet, T_2 is the total temperature of the air entering the engine, and the corrected airflow refers to the (mass flow entering the engine) x $\sqrt{T_2/519}$ / $(P_2/14.7)$.

Instrumentation

The engine/inlet interface plane was defined with a total pressure and total temperature array as shown in Figure 10. Each total pressure location involved both a high response (up to 800 Hz) Kulite transducer and a close-coupled, slow response (40 Hz) Statham transducer. For this test Kulite model XCEL-1 1/4 inch transducers were used. These transducers had a 0-50 psia range and had a small fine-meshed screen incorporated into each transducer mount to block any rust particles picked up in the inlet air heaters. The Statham transducers were model PA8569, with a 0-50 psia range. The Statham transducers were mounted in the bulletnose of the simulated engine and temperature conditioned with nitrogen to 200 ± 10°F. The Kulite transducers were exposed directly to the freestream total pressure and were not temperature conditioned.

Signal Conditioning

An electronic system was developed by Pratt & Whitney Aircraft to compensate for the intercept shift of the Kulite volt/psia calibration curve. It was assumed that the slope of the calibration curve would remain constant within the temperature envelope of this program. Figure 11 is a diagram of this electronic system. It was used to merge the high response Kulite signal with the low response Statham signal. The Statham signal was passed through a 1/4 Hz low pass filter and the Kulite signal was passed through a 1/4 Hz high pass filter. The resultant signals were merged and normalized to form a pressure signal independent of the Kulite shift in mean pressure with temperature. The merge equipment outlined in Figure 11 was enclosed in a temperature conditioned room. The final pressure signal was passed through a low pass filter which was designed to the filter characteristics described in Figure 12. This curve was developed by Pratt & Whitney Aircraft to account for the dwell time required for a compressor blade to respond to inlet distortion. The analog signal was finally digitized at one cut every 0.00096 seconds. For each data point analized for this study, 512 time slices were scanned.

Chapter III Review of Vorticity Theory

Nomenclature

Characters:

a	speed of sound
D	engine inlet diameter
e	unit directional vector
H	enthalpy
p	pressure
R	gas constant (gravity included)
s	specific entropy
S	entropy
t	time
T	temperature
x	vector cross product
∂	partial derivative
∇	vector operator del
γ	ratio of heat capacities
ω	vorticity

Subscripts:

1	station 1
2	station 2
r	radial direction
z	axial direction
Θ	circumferential direction

Discussion

The earliest reference promulgating the use of relative vorticity for the assessment of turbine engine stability is Reference 1. A summation of Reference 1 is contained in Reference 2. As an understanding of the basic tenets of the proposed vorticity approach is essential for this study, this chapter will briefly summarize References 1 and 2. The theory and equations in this chapter do not represent original work and are obtained from these references. A computer program to perform the vorticity calculations was developed for this study and does repre-

sent an original effort, although some of the subprograms have been adapted from different programs not originally written by the author.

In general form, Crocco's Theorem can be written as:

$$T\nabla S + u \times (\nabla \times u) = \nabla H + \partial u/\partial t$$

From basic thermodynamics:

$$\frac{s_2 - s_1}{R} = -\ln\left(\frac{p_{t2}}{p_{t1}}\right) + \frac{\gamma}{\gamma - 1}\ln\left(\frac{T_{t2}}{T_{t1}}\right)$$

For a constant total enthalpy, the combination of the above two equations yields:

$$-\frac{RT}{p_t}\nabla p_t + u \times (\nabla \times u) = \frac{\partial u}{\partial t}$$

The above equation can be rewritten in cylindrical coordinates. The component for the r direction is:

$$-\frac{RT}{p_t}\frac{\partial p_t}{\partial r} + \left(u_\theta \omega_z - u_z \omega_\theta\right) = \frac{\partial u_r}{\partial t}$$

and for the Θ direction is:

$$-\frac{RT}{p_t}\frac{1}{r}\frac{\partial p_t}{\partial r} + \left(u_z \omega_r - u_r \omega_z\right) = \frac{\partial u_\theta}{\partial t}$$

Let $p_t = p'/\bar{p}_t$, $u = u'\bar{a}$, $r = r'D/2$ and $\omega = \omega' 2\bar{a}/D$, where $\bar{p}_t$ is the average total pressure at the engine face, $\bar{a}$ is the average speed of sound at the engine face, D is the compressor diameter, and ω is the fluid vorticity. Rewriting the equations for radial and circumferential vorticity yields:

$$-\frac{1}{p'}\frac{\partial p'}{\partial r'} + \frac{\bar{a}^2}{a^2}\left(u_\theta' \omega_z' - u_z' \omega_\theta'\right) = \frac{V_{tip} N \bar{a}}{2\Pi a^2}\frac{\partial u_r'}{\partial t'}$$

and

$$-\frac{1}{\gamma p'}\left(\frac{1}{r'}\frac{\partial p'}{\partial \Theta}\right)+\frac{\bar{a}^2}{a^2}\left(u_z\omega_r - u_r\omega_z\right) = \frac{V_{tip}N\bar{a}}{2\Pi a^2}\left(\frac{\partial u_\theta'}{\partial t'}\right)$$

where N is the number of blades, V_{tip} is the velocity of the compressor blade tip, and $t = t'\Pi D/(V_{tip}N)$ and is a function of the blade passing frequency.

After considerable order-of-magnitude analysis, the above equations reduce to:

$$\omega_r' = \frac{1}{\gamma p' u_z'}\left(\frac{1}{r'}\frac{\partial p'}{\partial \Theta}\right)$$

and

$$\omega_\theta' = \frac{1}{\gamma p' u_z'}\left(\frac{\partial p'}{\partial r'}\right)$$

but $u_z' = u_z/a = u_z/(\bar{u}_z/\bar{M}) = \bar{M}u_z/\bar{u}_z =$

$$\bar{M}\left(\frac{(p_t - p_s)(2/\rho)}{(\bar{p}_t - p_s)(2/\rho)}\right)^{.5} = \bar{M}\left(\frac{p_t - p_s}{\bar{p}_t - p_s}\right)^{.5}$$

Recalling that $\omega_r' = \omega_r D/2a$ and $\omega' = \omega_\Theta D/2a$, the final equations are obtained:

$$\omega_r = \frac{2a}{\gamma D p' \bar{M} Q}\left(\frac{1}{r'}\frac{\partial p'}{\partial \Theta}\right) \qquad \frac{\text{ft./sec.}}{\text{ft.}}$$

and

$$\omega_\theta = \frac{2a}{\gamma D p' \bar{M} Q}\left(\frac{\partial p'}{\partial r'}\right) \qquad \frac{\text{ft./sec.}}{\text{ft.}}$$

where

$$Q = \left(\frac{p_t - p_s}{\bar{p}_t - p_s}\right)^{.5}$$

The final equations described above are those which were programed into the automated calculation procedure. A listing of the computer program is contained in Appendix A.

As each of the terms for radial and circumferential vorticity are vectors, the absolute value of the total vorticity was obtained through the Pythagorean theorem. The absolute value of the total vorticity, hereafter termed the normal vorticity, was deemed of primary importance as this value should correlate directly to the total pressure gradient at the engine face. As stated previously, the total pressure gradient should correlate with the turbulence at the engine face.

Chapter IV Data Analysis

Steady State Data

As described in Chapter II, the data from the calibration of four distortion screens were evaluated. Only the data generated at the screen design airflows were used. The steady state data were processed through the automated calculation procedure to obtain values of normal vorticity.

Transient Data

Next the high-response total pressure data, termed dynamic data, were processed. As described in Chapter II, each dynamic data point consisted of 512 scans, digitized at 0.00096 seconds/cut, which had been processed and filtered according to Figure 12. Each dynamic data point was scanned to determine the worst case of distortion. As described in Chapter I, the criterion for the worst distortion pattern was (maximum total pressure - minimum total pressure)/average total pressure at the engine face, commonly referred to as $\Delta p/p$. The distortion patterns for the worst cases were obtained through use of the computer program listed in Appendix A. Bad Kulite readings were determined by visual inspection of the raw data. The computer program substituted values for the bad Kulite readings by using a weighted average of the surrounding pressure probes.

Turbulence

Next, the standard deviation of each high response pressure probe from the steady-state pressure reading was obtained. The standard deviation of the high response pressure data was termed

"turbulence." "Turbulence" patterns and average "turbulence" values were obtained.

Vorticity

Finally, the steady-state pressure data were processed through a computer program developed to calculate and plot the normal vorticity at the engine inlet. A listing of this program is contained in Appendix A. The computer print-out from the four input cases immediately follows the listing. The development of the principal vorticity equations is contained in Chapter III.

Analysis of Data

Figures 13 through 16 compare the steady-state pressure distortion pattern, the worst-case pressure distortion pattern, the pressure "turbulence" distortion pattern, and the normal vorticity pattern for each of the four screens. A comparison of the steady-state and the worst-case pressure distortion patterns shows that the isobar of average pressure changes little. Also, the average compressor face total pressure does not change between the steady-state and worst-case pressure distortion. Therefore, all that need be done is to determine a modifier to increase the above average steady-state pressure readings and decrease the below average pressure readings, while maintaining the same average pressure. If such a modifier could be obtained, an accurate estimate of the worst case distortion pattern would be easily and economically available.

Next, the standard deviation of the high response pressure from the corresponding steady state pressure, termed "turbulence,"

and the normal vorticity patterns were compared. The regions of high and low pressure "turbulence" do not compare well with the regions of high and low normal vorticity. Therefore, normal vorticity alone is not an accurate predictor of "turbulence" level. Also, there is no evidence to indicate that average normal vorticity correlated with average "turbulence" level.

The lack of correlation between normal vorticity and "turbulence" is not understood. Some high frequency "turbulence" could result from the airflow through the distortion screen. This type of "turbulence" would not be related to normal vorticity. The distortion screen mesh size is assumed to have little effect on the "turbulence" level however, since the 28.7 inches between the distortion screen and the pressure instrumentation would permit considerable dissipation of the fine grained "turbulence." Any remaining fine grained "turbulence" would be eliminated in filtering the data according to Figure 12.

In an attempt to correlate the average "turbulence" level with average normal vorticity and the difference between steady state and dynamic $\Delta p/p$, Table 2 was developed.

Test / Data Point	Average Turbulence	$\Delta p/p$ Difference	Ave. Normal Vorticity	Steady State $\Delta p/p$
HA-08/10	0.042	0.0266	652	0.2213
HA-16/10	0.092	0.0523	610	0.1774
HA-17/12	0.070	0.0283	383	0.2627
HA-18/24	0.028	0.0375	484	0.1766

Table 2

Examination of Table 2 reveals that nothing correlates on macroscopic terms. The objective of this study was to have the

column of the difference between steady state and dynamic $\Delta p/p$ correlate with the average normal vorticity and the average "turbulence." As described above, average normal vorticity is not a good indicator of average "turbulence." Table 2 demonstrates that average normal vorticity is not a good correlator of $\Delta p/p$ difference either.

Analysis of Probe-by-Probe Data

Next, the correlation between $\Delta p/p$ difference and normal vorticity was approached on a probe-by-probe basis. The pressures in the distortion patterns were normalized by dividing them with the average total pressure of the entire distortion pattern. The difference between the lowest normalized pressure from the steady-state pressure distortion pattern and the lowest normalized pressure from the worst-case pressure distortion pattern was obtained. This difference was compared to the normal vorticity at the location of the lowest pressure reading from the steady-state distortion map. In a similiar manner, normal vorticity was compared with the difference between the highest normalized pressure readings from the steady-state and worst-case pressure distortion patterns. Figure 17 summarizes the results of this comparison.

Although the normal vorticity values do appear to be a function of the normalized pressure difference, the correlation is not good enough to predict the worst-case distortion to within 1% $\Delta p/p$. Of particular concern is the negative slope of the data points from test HA-18. The characteristic of the HA-18 data prohibits further analysis of the available data.

Chapter V Recommendations for Additional Analysis

Shortcomings of Present Analysis

Data storage problems have prohibited additional data analysis. Flaws in the problem approach and data analysis are presented to enhance additional studies in this field and to indicate weak areas of this study which may have led to unjustified conclusions.

The objective of this study was to develop a technique for predicting the worst-case pressure distortion produced by a distortion screen at the entrance of a gas turbine engine. The criterion used to determine the worst-case pressure distortion was found to be flawed and should be changed in any additional studies. Distortion severity is measured by the depth, extent, and location of the pressure defect at the engine face. For this study, however, engine characteristics were ignored so that distortion location is not of importance. The criterion used to determine worst-case pressure distortion was (maximum total pressure - minimum total pressure) / average total pressure at the engine face. This criterion is a poor measure of the depth and extent of pressure distortion and should be improved in additional efforts. A step in the right direction would be the use of (average total pressure - minimum total pressure) / average total pressure at the engine face. Although this criterion will improve the evaluation of the depth of the pressure defect, it does not address the extent of the pressure defect and could be improved further.

Insufficient statistical tools were exercised during the evaluation of the probe-by-probe data. For this study the difference between the lowest normalized pressure from the steady-state pressure distortion pattern and the lowest normalized pressure from the worst-case pressure distortion pattern was obtained. This difference was compared to the normal vorticity at the location of the lowest pressure reading from the steady-state distortion pattern. This approach was too simplified for a problem as statistical as screen-induced pressure distortion. In some instances, when the location and value of the lowest normalized pressure on the steady-state distortion pattern had been determined, an examination of the worst-case distortion pattern revealed that the normalized pressure at the same location had actually increased, although the total distortion level had worsened. Any additional studies should include an improved approach to comparing a worsening of pressure distortion levels with normal vorticity.

This study has emphasized the vorticity at the locations of the lowest and highest total pressure in the steady-state distortion pattern. If the amount of "turbulence" in screen-induced distortion occurs in the regions of the highest pressure gradient, the lowest normalized pressure in the worst-case distortion pattern may well occur at a point different than the point of lowest normalized steady-state pressure. Therefore, to obtain a more accurate estimate of the worst-case pressure distortion using only steady-state pressure measurements, the vorticity at each

location should be applied in some fashion to the steady-state distortion map.

Improved Test Program

The objectives of the screen calibration program were substantially different than those of this study. To obtain a more worthwhile effort, a test program should be developed and directed towards the prediction of worst-case screen-induced pressure distortion. The improved test program would produce data which would enhance a distortion prediction effort.

First, several screens should be tested. The screens should cover a large range of depth, extent and location. The distortion screens should consist of an array of classical distortion patterns, such as 180° circumferential distortion and radial distortion located at both the hub and tip of the imaginary fan blades, as well as complex distortion patterns resembling those generated by an actual aircraft inlet. Data should be obtained from the distortion screens over a range of Reynolds Number Index and corrected airflow (as defined in Chapter II). The breadth of this proposed test plan should provide the data required for the most rigorous analysis.

Second, every effort should be made to assure correct data. Pressure probes should not be located behind seams in the distortion screen where weld beading could produce non-representative "turbulence." The signals from the high-response pressure transducers should be carefully analized to verify that electronic noise is not degrading the signal quality. In short, every effort

should be made to assure the highest quality data.

Third, all data should be generated with a "cold-pipe" engine rather than an actual gas turbine engine. The advantages of a "cold-pipe" engine are twofold. First, there would be no need to expose an engine to the high levels of distortion that would be covered in a complex test matrix. The level of risk, as well as data reduction requirements and test cost, could therefore be reduced. Second, use of a "cold-pipe" engine would ensure a uniform static pressure at the distortion measurement plane. Data generated under uniform pressure conditions would apply to several different engines, where data generated behind a certain engine and its peculiar flow redistributions may apply only to one engine or family of engines.

Chapter VI Conclusions

The objective of this study was to develop an empirical technique using normal vorticity to predict the worst-case total pressure distortion produced by an inlet distortion screen at the entrance of a gas turbine engine. That objective has not been met. Modifications to the local computer system have caused the data tapes to be unreadable and additional study of the data is not possible. Nevertheless, several conclusions can be drawn from the studies.

Bulk quantities, such as average normal vorticity or average turbulence, do not relate to the differences between the steady-state and worst-case pressure distortion patterns. These differences must be estimated using probe-by-probe evaluation of the steady-state data.

The available data do not indicate any correlation between normal vorticity and the standard deviation of the high-response pressure measurements. The lack of correlation may be caused by phenomena not yet understood. Other causes may be that high-response pressure probes were located behind the weld at the screen interfaces and experienced non-representative "turbulence," or that electromagnetic interference or faulty pressure probes compromised the quality of the data. Future studies should choose probe locations carefully and scrutinize the data so that areas of examination can be narrowed to physical phenomena.

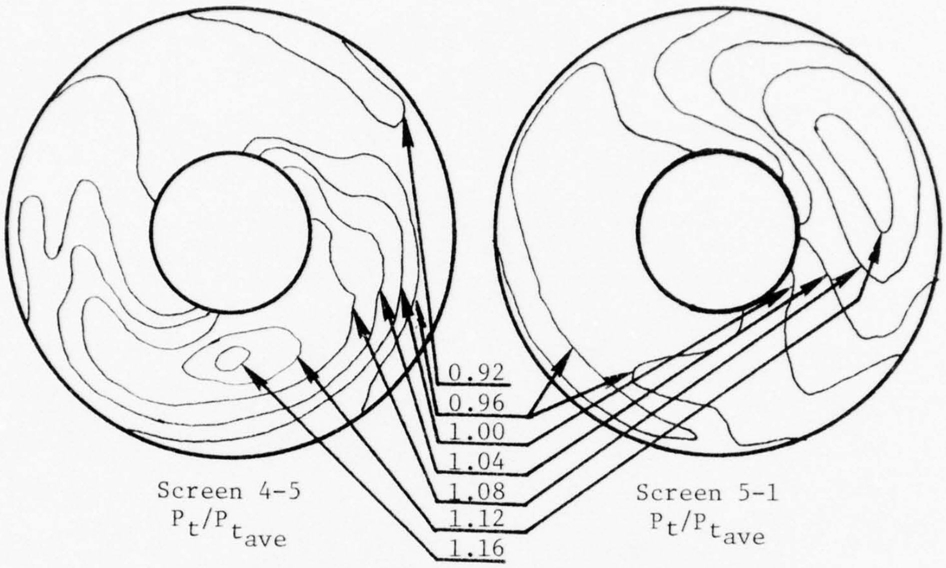
Limited data has indicated that there is a relationship between normal vorticity and the differences between the steady-

state and worst-case pressure distortion patterns. This relation appears to be influenced by Reylolds Number Index (RNI). (See Figure 6.) Further study should be performed to confirm or refute this relationship.

Finally, this study has outlined a test program which would complement an effort to predict worst-case pressure distortion from only steady-state pressure measurements. Normal vorticity has been shown to be related to the difference between steady-state and worst-case screen-induced distortion. Efforts to refine this relationship should prove successful with improved data and additional studies.

Figures

Goal Distortion Patterns for Screen Design



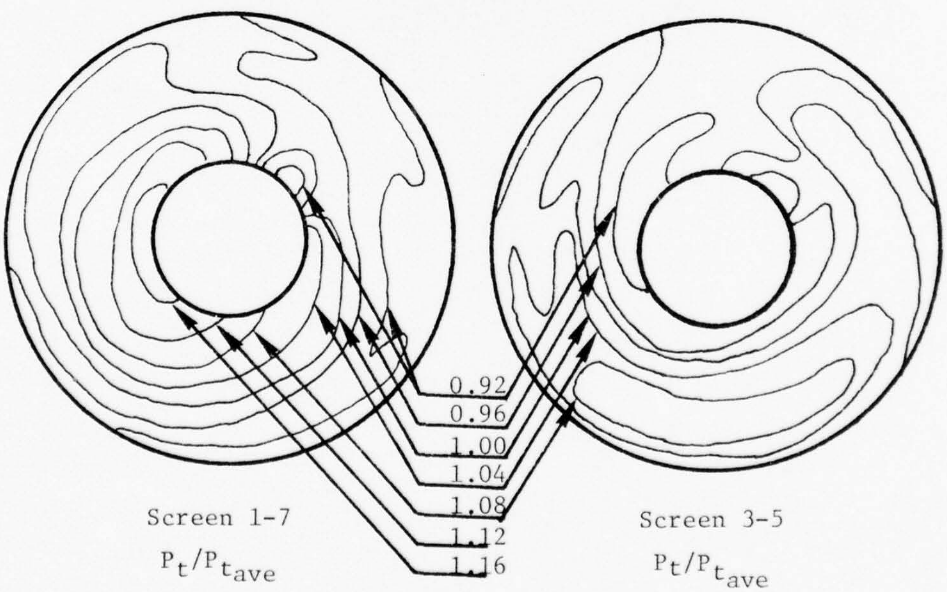
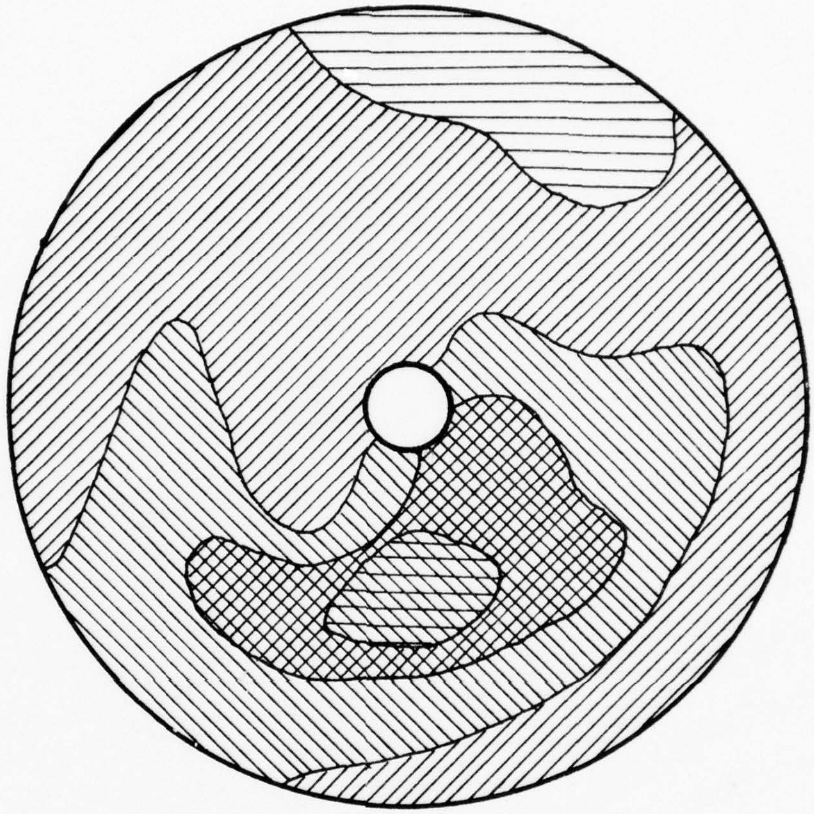


Figure 1

Screen Blockage and Grid Size

Screen 4-5F

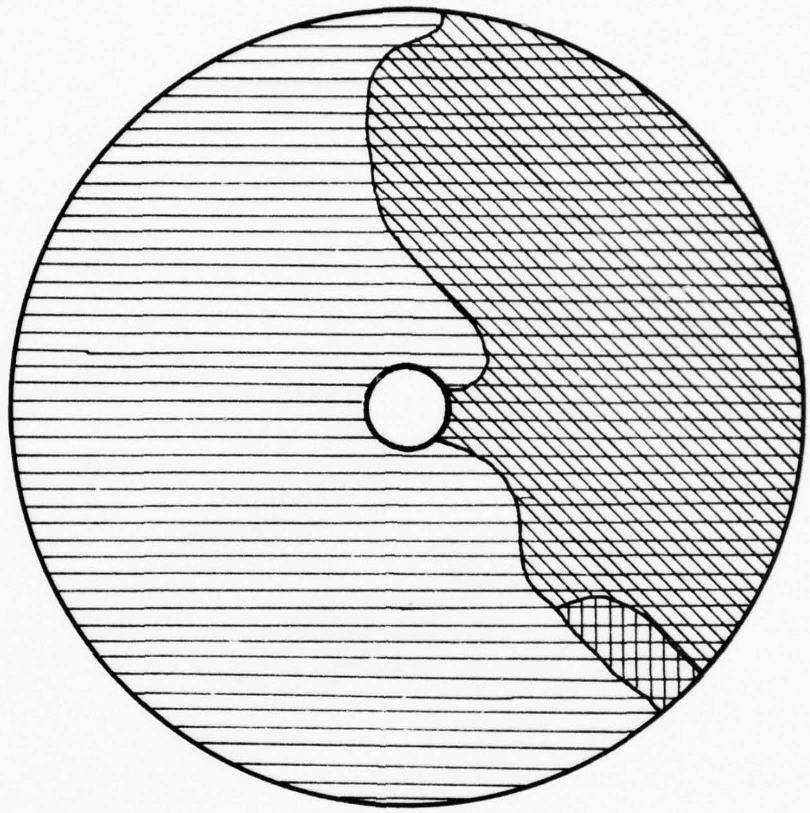


% Total Area	% Blockage	Screen Size
3.5	23.9	1 x 1 x .125 (Basic Grid)
13.6	23.6	2 x 2 x .063 inches
24.8	34.4	3 x 3 x .063 inches
49.5	78.1	8½ x 8½ x .063 inches
8.7	81.3	9 x 9 x .063 inches

Figure 2

Screen Blockage Area and Grid Size

Screen 5-1F

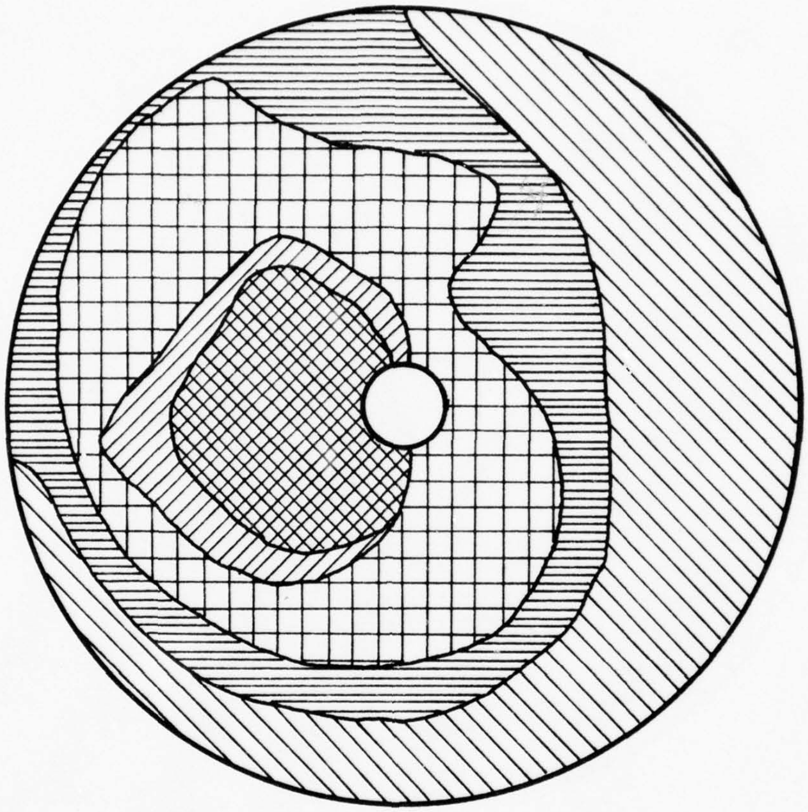


% Blockage	Screen Size
53.1	5 x 5 x .063 inches
86.3	10 x 10 x .063 inches
23.9	1 x 1 x .125 (Basic Grid)

Figure 3

Screen Blockage and Grid Size

Screen 1-7F

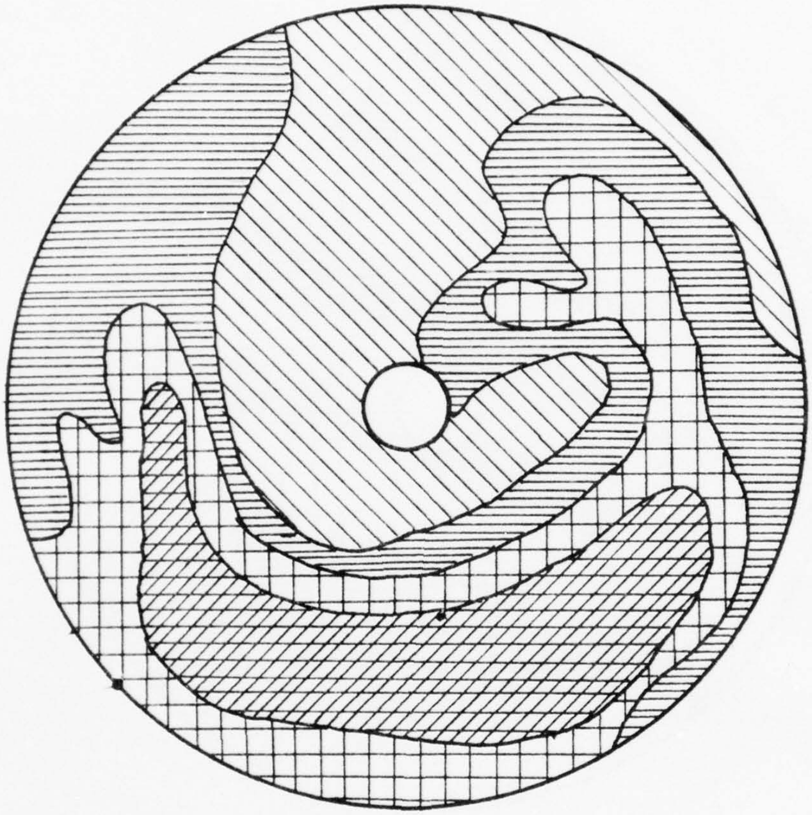


% Total Area	% Blockage	Screen Size
9.2	23.9	1 x 1 x .125 (Basic Grid)
6.4	23.6	2 x 2 x .063 inches
29.3	29.0	2½ x 2½ x .063 inches
20.6	53.1	5 x 5 x .063 inches
34.5	57.2	5½ x 5½ x .063 inches

Figure 4

Screen Blockage and Grid Size

Screen 3-5F



% Total Area	% Blockage	Screen Size
31	57.2	5½ x 5½ x .063 inches
25	48.8	4½ x 4½ x .063 inches
23	29.0	2½ x 2½ x .063 inches
21	23.9	1 x 1 x .125 (Basic Grid)

Figure 5

Test Cell, Schematic of Installation

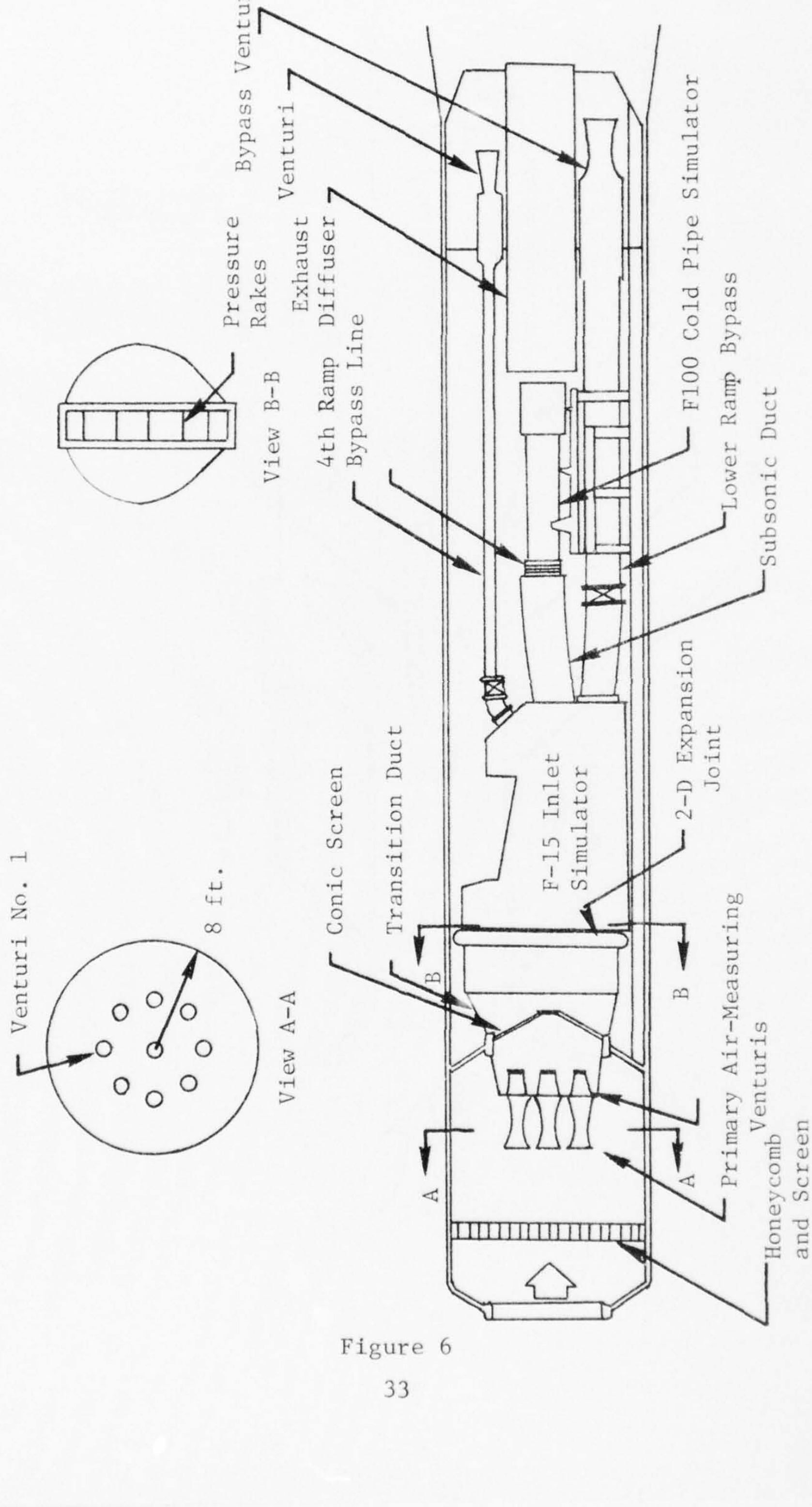
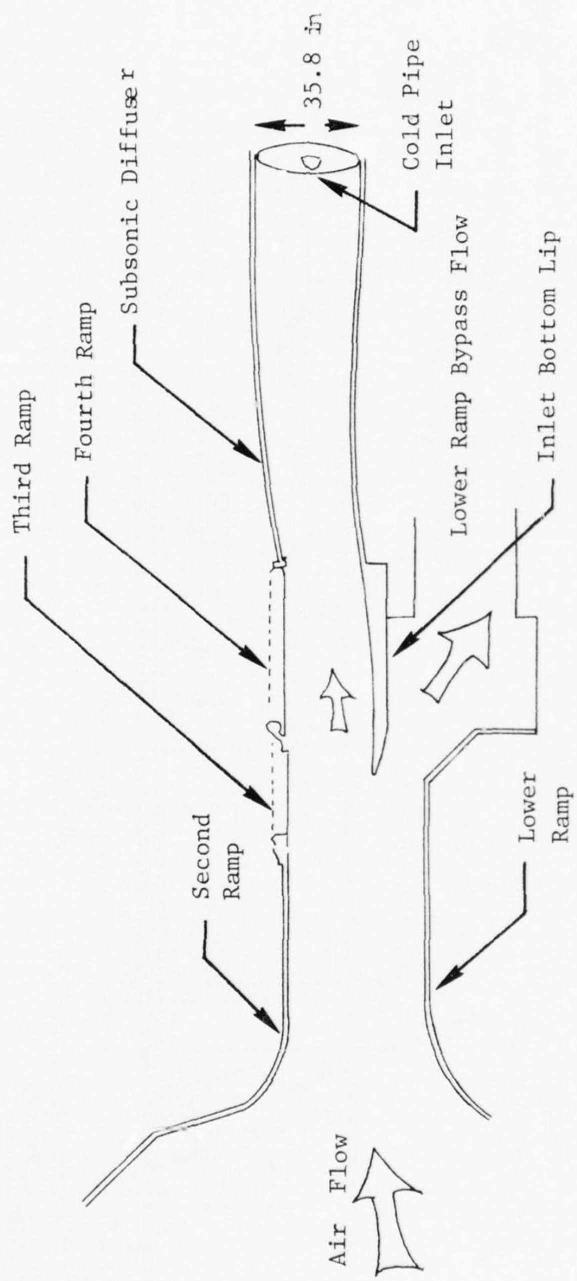


Figure 6

Schematic of Inlet Simulator



Schematic of Subsonic Duct

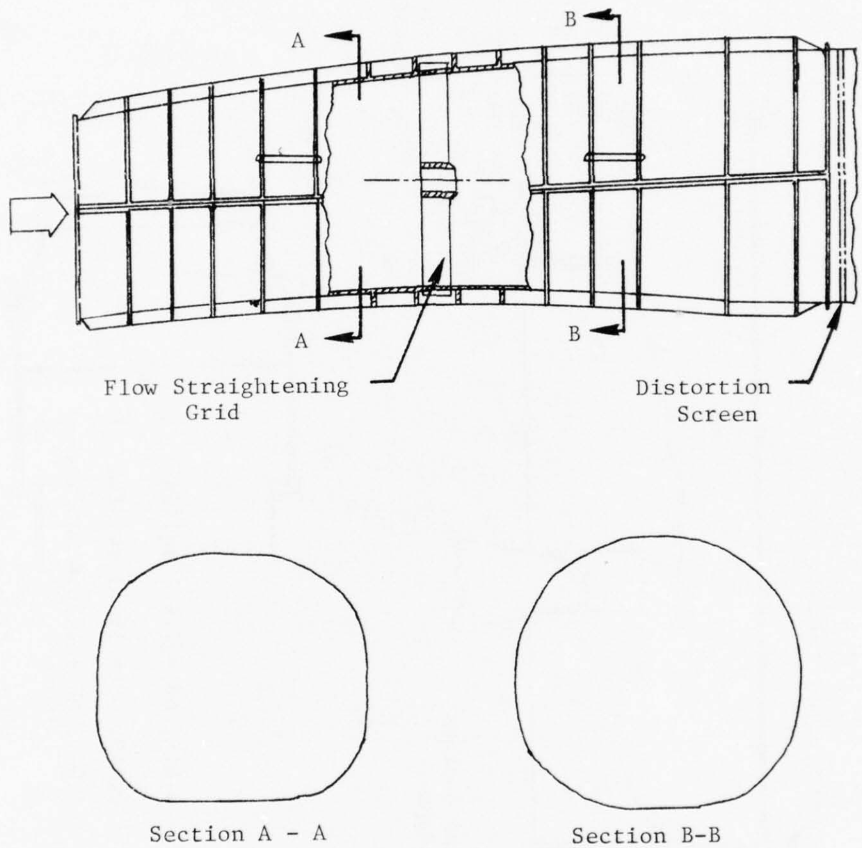


Figure 8

Schematic of the Cold Pipe

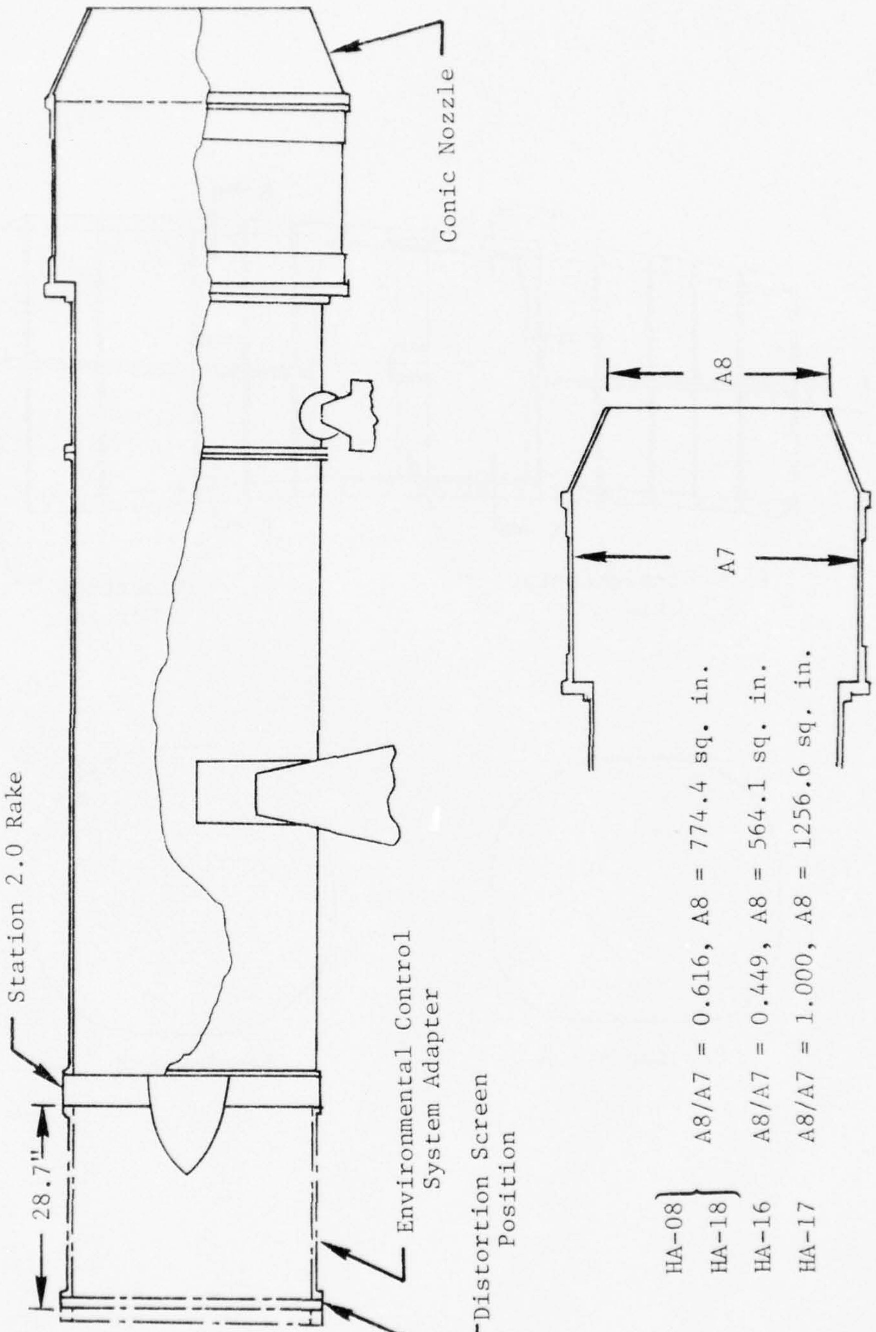
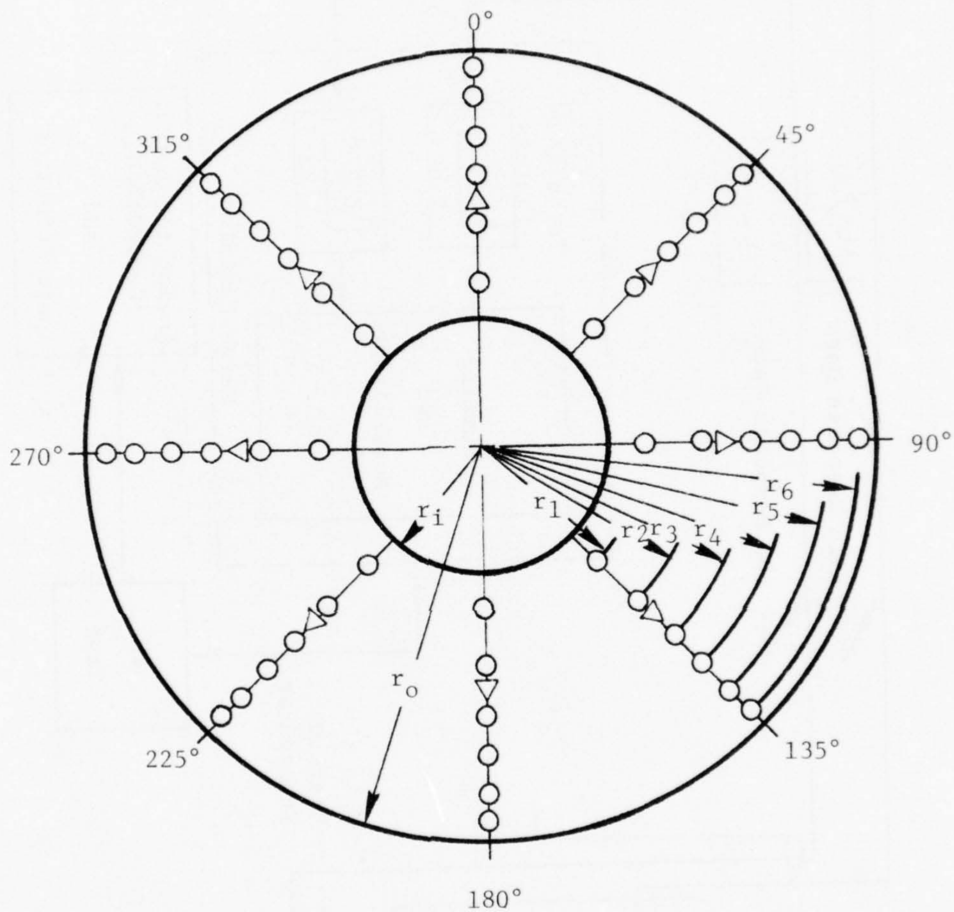


Figure 9

Engine Inlet Instrumentation Diagram

(View Looking Upstream)



○ Total Pressure

△ Total Temperature

r_i = 5.65 inches
r_1 = 7.22 inches
r_2 = 9.92 inches
r_3 = 11.99 inches
r_4 = 13.76 inches
r_5 = 15.32 inches
r_6 = 16.74 inches
r_o = 17.39 inches

Figure 10

Data Conditioning System

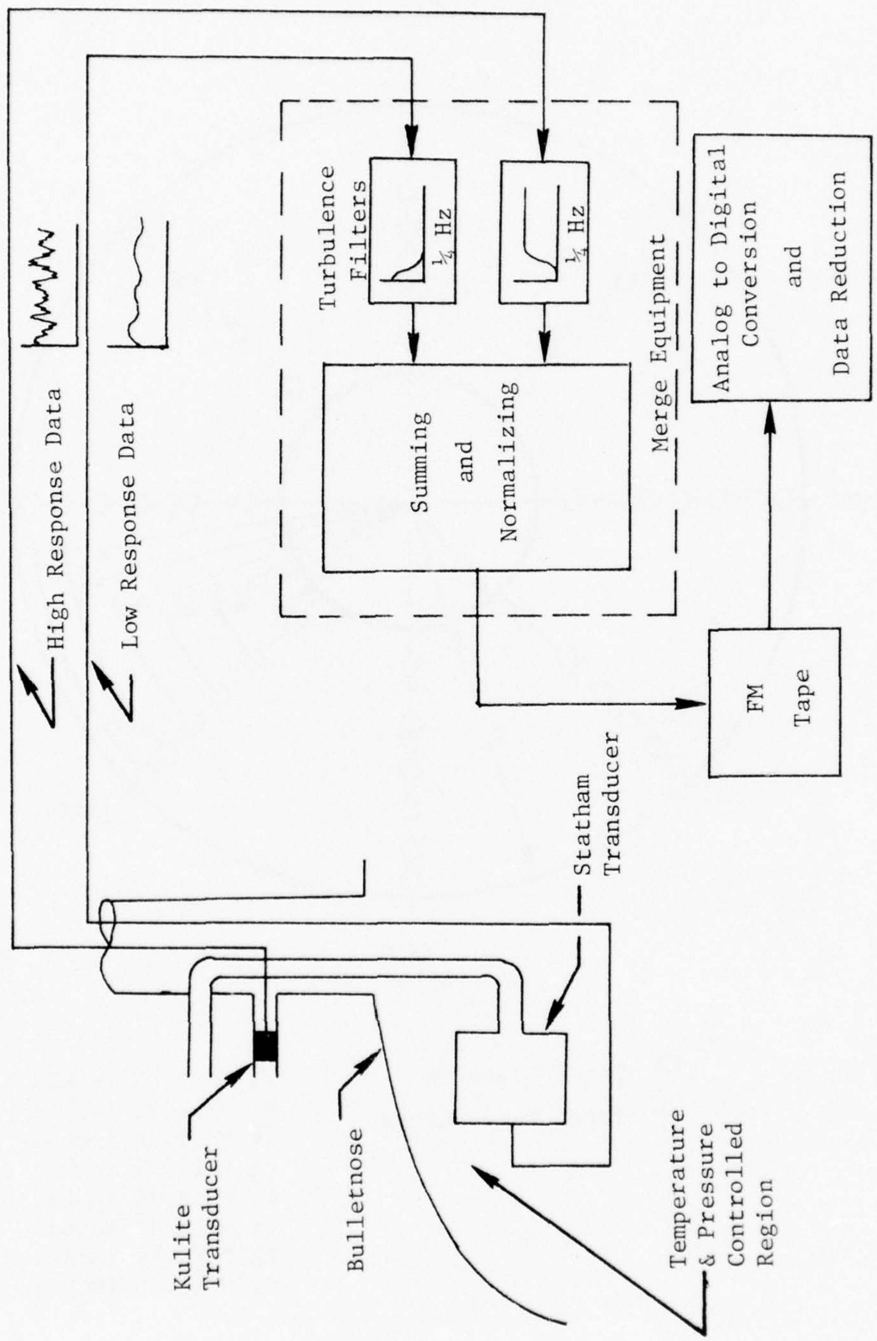


Figure 11

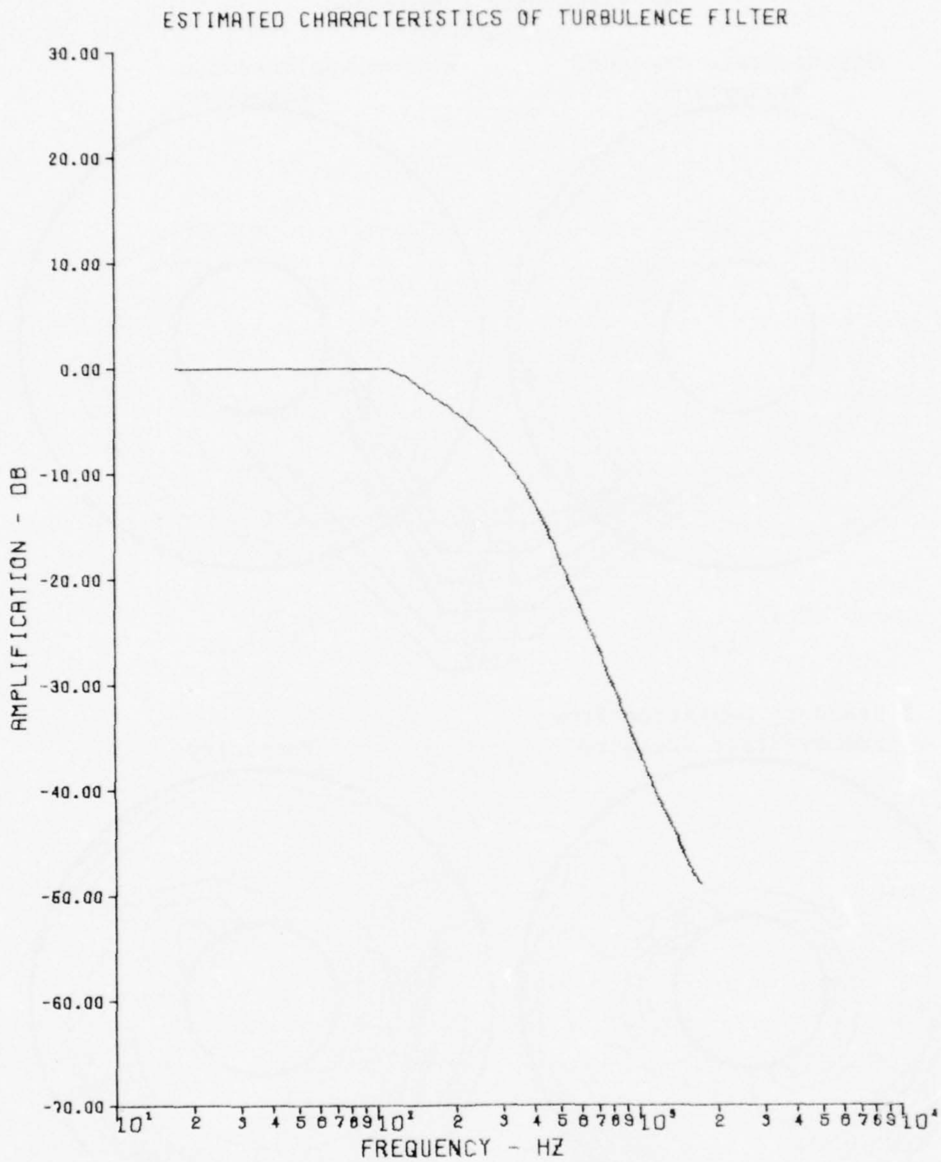

ESTIMATED CHARACTERISTICS OF TURBULENCE FILTER
AMPLIFICATION - DB
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
FREQUENCY - HZ

Figure 12

Test HA-08 Data Comparison
Screen 4-5F

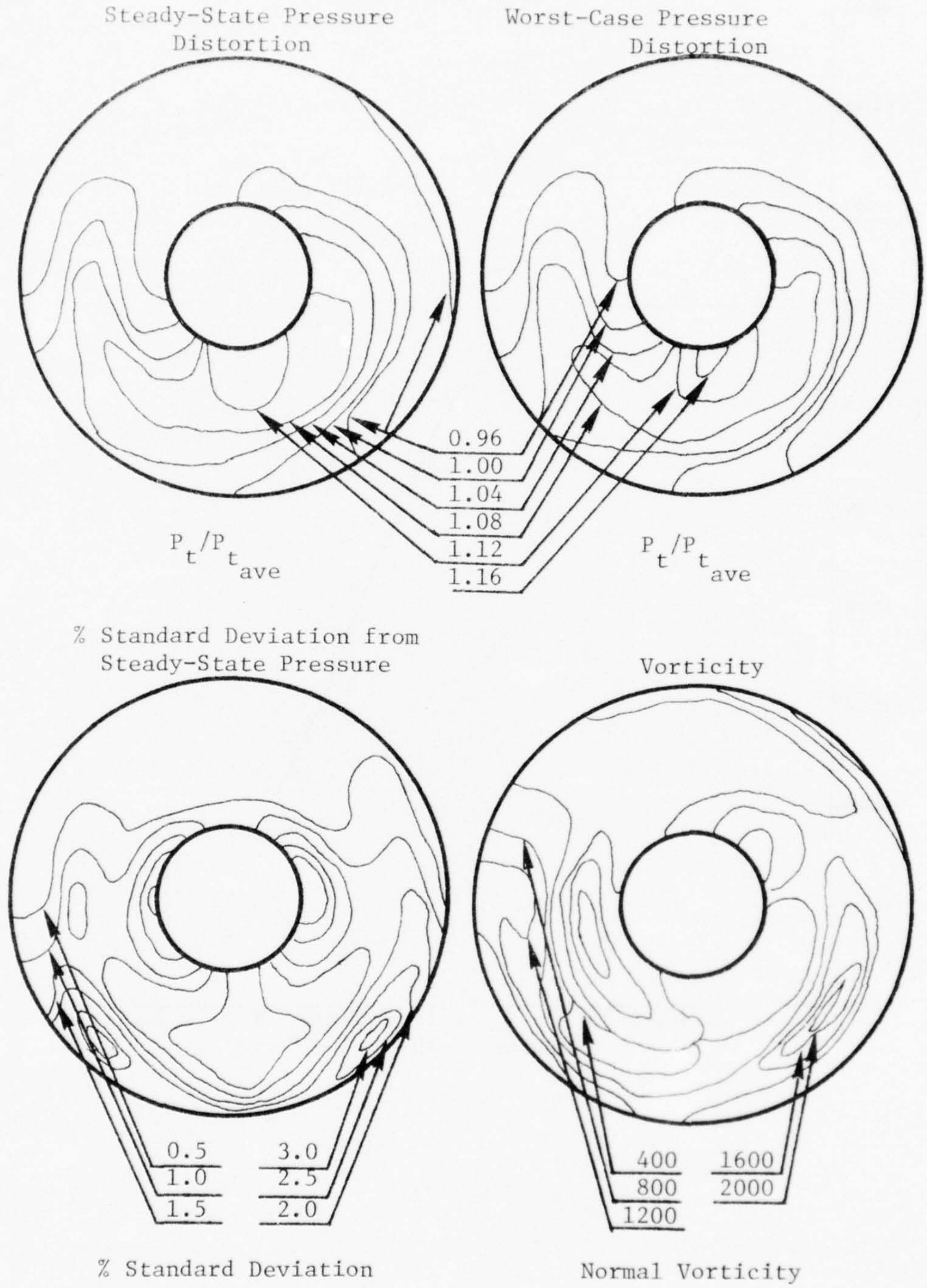


Figure 13

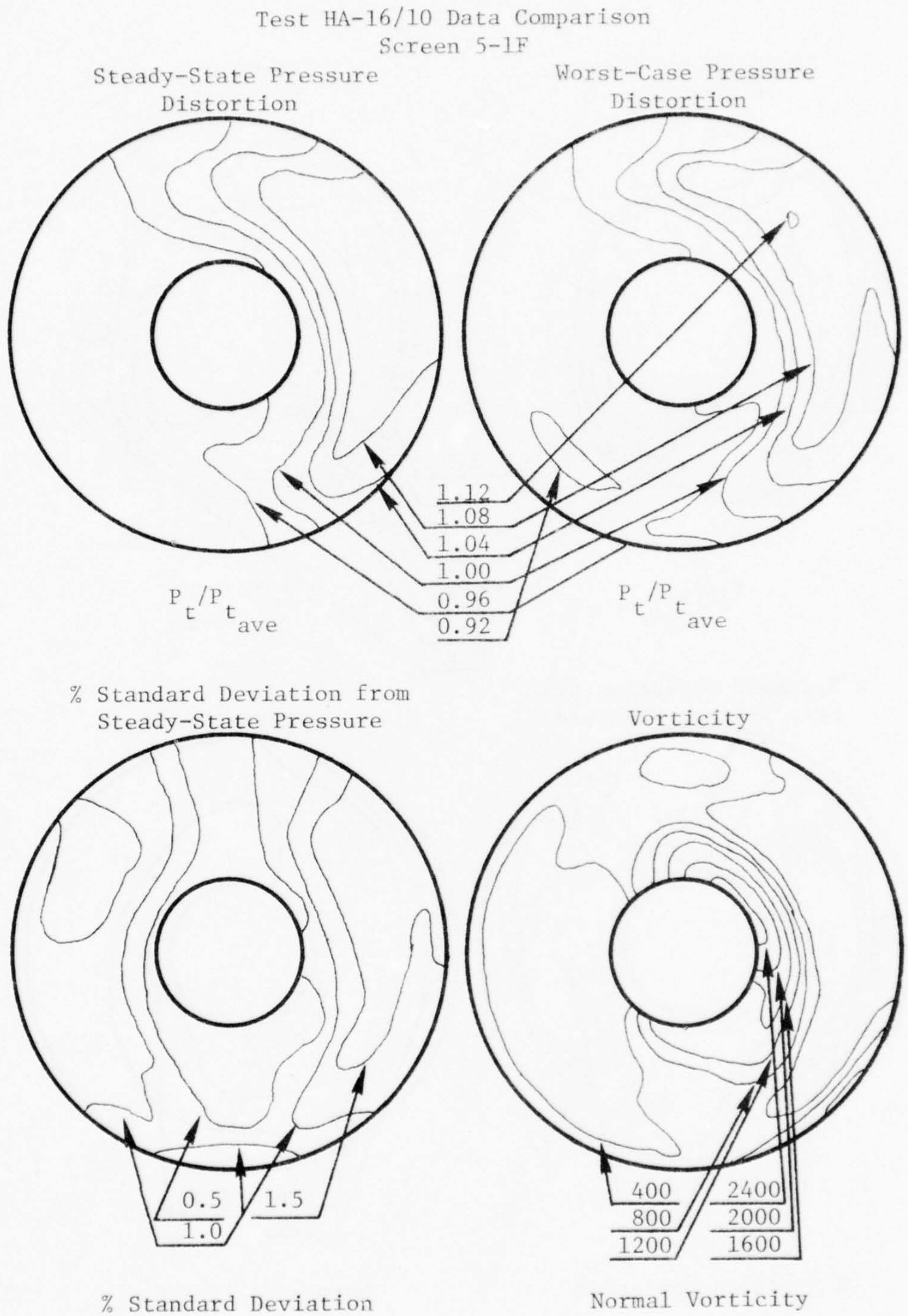

Test HA-16/10 Data Comparison
Screen 5-1F
Steady-State Pressure Distortion
Worst-Case Pressure Distortion
1.12
1.08
1.04
1.00
0.96
0.92
Pt/Pt ave
Pt/Pt ave
% Standard Deviation from Steady-State Pressure
Vorticity
0.5
1.0
1.5
400
800
1200
2400
2000
1600
% Standard Deviation
Normal Vorticity

Figure 14

Test HA-14/12 Data Comparison
Screen 1-7F

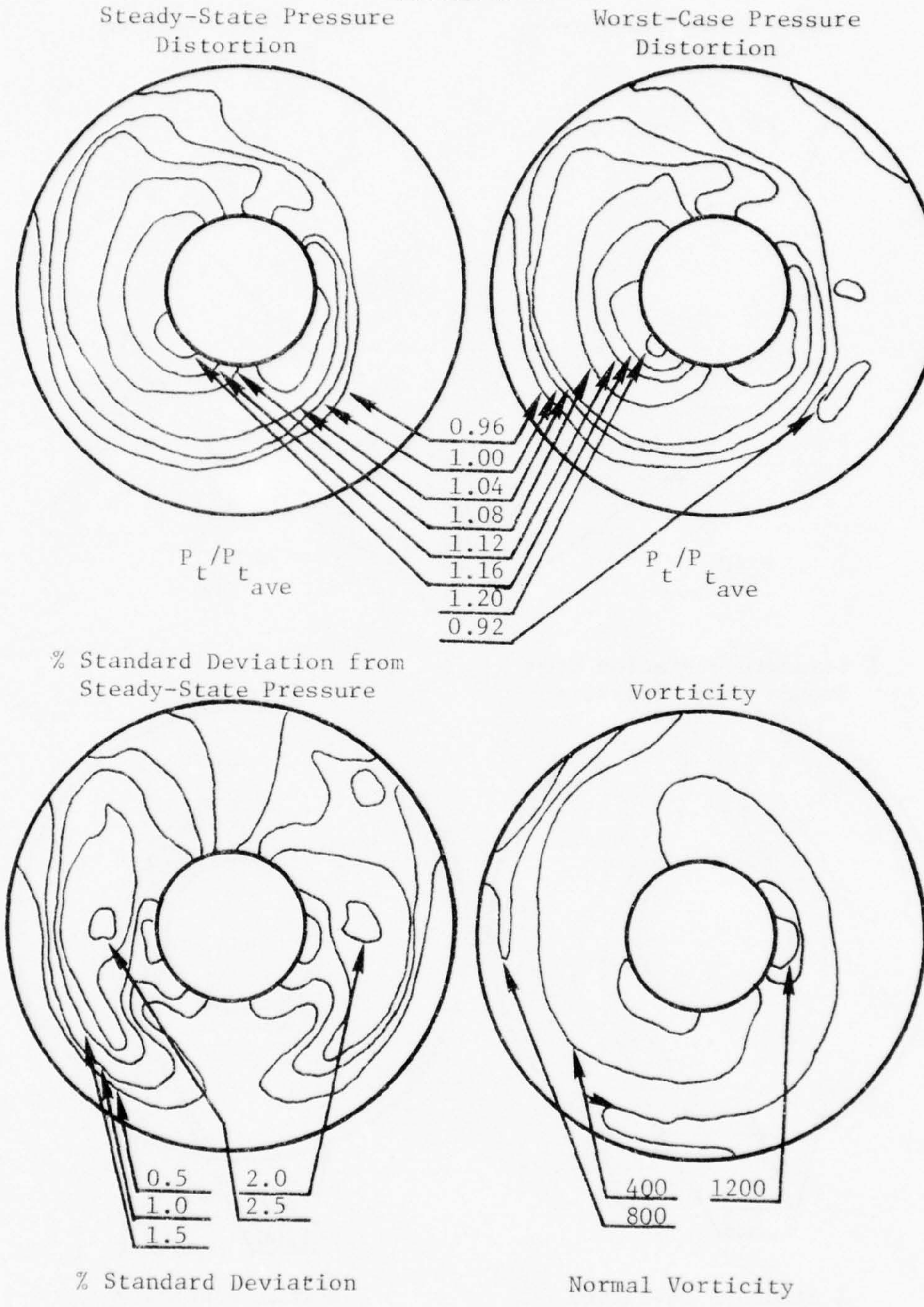


Figure 15

Test HA-18/24 Data Comparison
Screen 3-5F

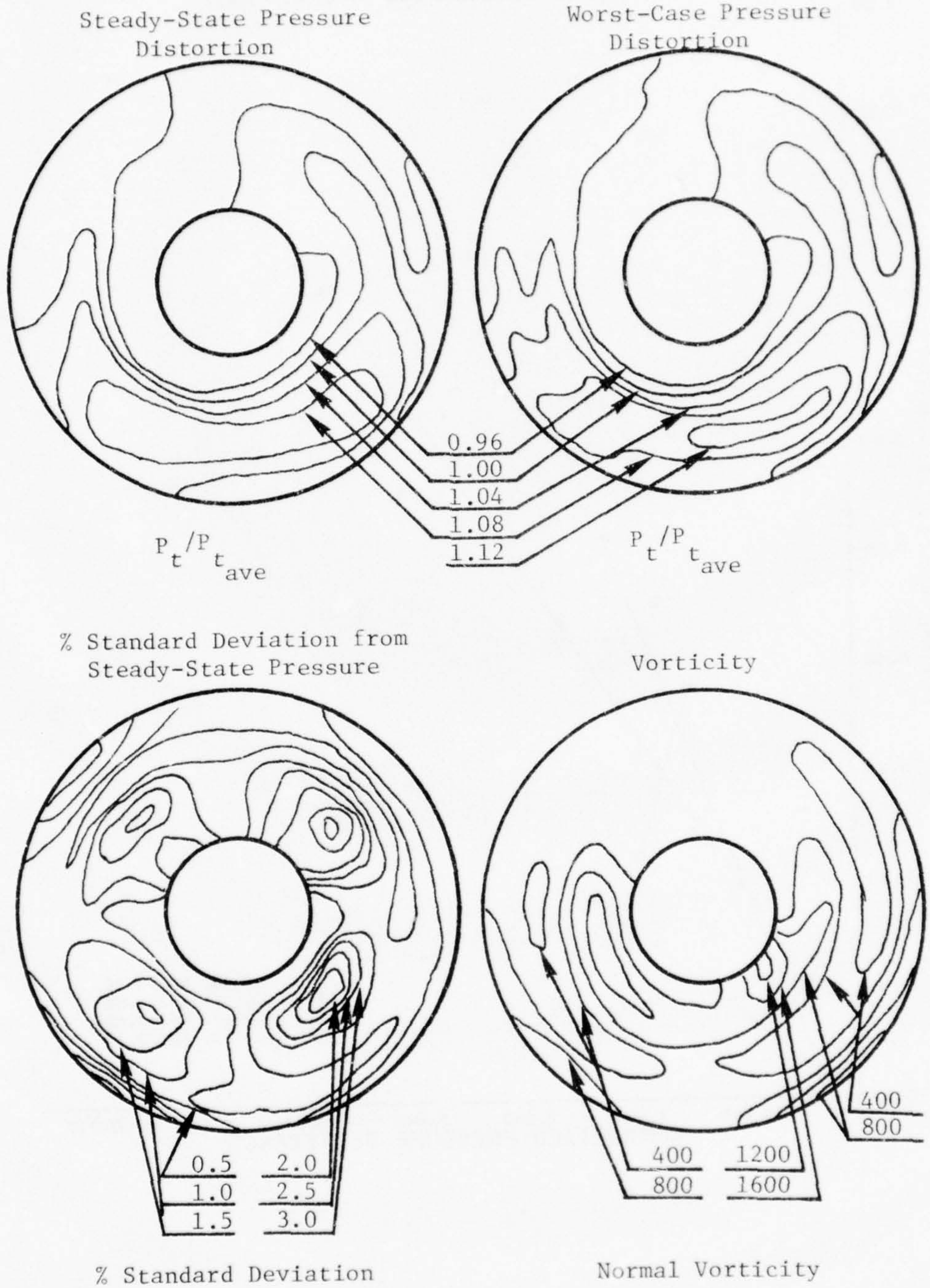


Figure 16

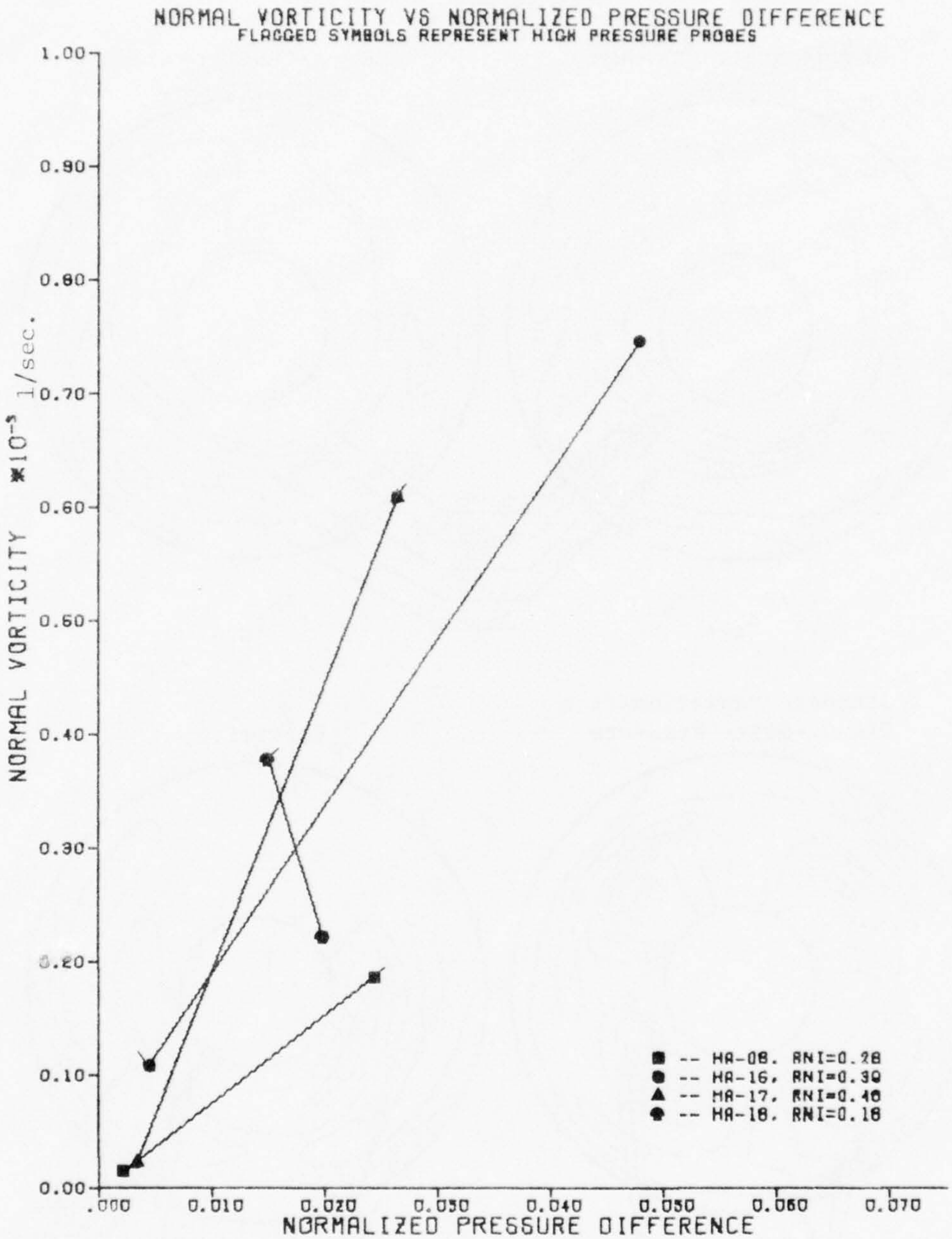

NORMAL VORTICITY VS NORMALIZED PRESSURE DIFFERENCE
FLAGGED SYMBOLS REPRESENT HIGH PRESSURE PROBES
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
NORMAL VORTICITY *10⁻³ 1/sec.
.000
0.010
0.020
0.030
0.040
0.050
0.060
0.070
NORMALIZED PRESSURE DIFFERENCE
-- HA-08, RNI=0.28
-- HA-16, RNI=0.39
-- HA-17, RNI=0.46
-- HA-18, RNI=0.16

Figure 17

Text References

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23. Kimzey, W. F. and McIlveen, M. W., Analysis and Synthesis of Distorted and Unsteady Turbo Engine Inlet Flow Fields, AIAA Paper 71-668, June 1971.

Appendix A

```
      PROGRAM VORTEX ( OUTPUT, TAPE5, TAPE6=OUTPUT )
      COMMON / SETUP1 / ANGLES(10), RADII(10), TITLE(8), TIME
      COMMON / SETUP2 / DELPR, RIN, ROT, NOT, NOA, DELAN, NORAKS, APOPP,
     1                  DELVOR
      COMMON / SETUP3 / GRADR(10,10), GRADTH(10,10)
      COMMON / SETUP4 / TT2, PS2, AREA, AIRFLO
      COMMON / SETUP5 / PTOPR(10,10), PTOPR(10,10), I2(10,10)
      DIMENSION DATA(50), IPROBS(12)
      DATA IPROBE, ISCREEN, NPLOT1, TIME, I2 / 2*0., 2, 0., 100*1H
C
C   INPUT DEFINITIONS
C     * = DEFAULT VALUE
C    IPROBE        THE NUMBER OF BAD PROBES IN THE DATA
C                  MAXIMUM NUMBER OF 12
C    IPROBS        LIST OF THE BAD PROBE NUMBERS, IN ORDER
C    ISCREEN       FOR AUTOMATIC STATISTICAL SCREENING OF DATA
C               *  0 = NO SCREENING
C                  1 = SCREENING
C    DELPR         FACE PATTERN PRESSURE RATIO INCREMENT
C    DELWCIR       FACE PATTERN CIRCUMFERENTIAL VORTICITY INCREMENT
C    DELAN         FACE PATTERN ANGLE INCREMENT IN DEGREES
C    RIN           STATION INNER RADIUS IN INCHES
C    ROT           STATION OUTER RADIUS IN INCHES
C    NOT           NUMBER OF PROBES PER RAKE
C                  MINIMUM NUMBER OF 3, MAXIMUM NUMBER OF 10
C    NORAKS        NUMBER OF RAKES
C    DATA          ENGINE FACE TOTAL PRESSURES IN PSIA
C    TITLE         USER INPUT TITLE INFORMATION
C    RADII         RING RADII IN INCHES
C    ANGLES        RAKE POSITIONS IN DEGREES
C    PS2           ENGINE FACE AVERAGE STATIC PRESSURE
C    TT2           ENGINE FACE AVERAGE TOTAL TEMPERATURE IN DEGREES R
C    AIRFLO        ENGINE FACE CORRECTED AIRFLOW
C    NPLOT1        METHOD OF DATA INPUT
C                  1 = TIME INPUT FROM TAPE
C               *  2 = CARD INPUT
C    TIME          FOR TAPE INPUT, THE TIME OF THE DESIRED DATA
C
C
C   INITIALIZE STATION 2.0 CONDITIONS
C
      DATA RIN, ROT, NOT, NORAKS, DELPR / 5.65, 17.387, 6, 8, 0.04 /
      DATA RADII / 7.277, 9.919, 11.992, 13.756, 15.313, 16.736, 4*0. /
      DATA ANGLES /  0., 45., 90., 135., 180., 225., 270., 315. ,2*0. /
```

```
      DATA DELAN, DELVOR, ISWITCH / 5., 400., 1 /                         VORT0450
      NAMELIST / DATIN / IPROBE, DELPR, AIRFLO, DELVOR, RIN,              VORT0460
     1                   ROT, NOT, DATA, TITLE, RADII, IPROBS, ANGLES,    VORT0470
     2                   PS2, TT2, ISCREEN, NORAKS, TIME, NPLOT1, DELAN   VORT0480
      CALL LISTER                                                         VORT0490
      NOA = NORAKS + 1                                                    VORT0500
    1 READ (5,DATIN)                                                      VORT0510
      IF ( EOF(5) .NE. 0. ) STOP                                          VORT0520
      IF ( TITLE(1) .EQ. 1. ) READ (5,100) TITLE                          VORT0530
  100 FORMAT (8A10)                                                       VORT0540
C                                                                         VORT0550
C                                                                         VORT0560
C     READ DATA                                                           VORT0570
C                                                                         VORT0580
C     WRITE OUT CONTROL PARAMETERS                                        VORT0590
C                                                                         VORT0600
      WRITE (6,101) TITLE                                                 VORT0610
 101  FORMAT ( 1H1, //, 1X, 8A10 )                                        VORT0620
      WRITE (6,106)                                                       VORT0630
  106 FORMAT ( //, 27X, "VORTICITY MAP PROGRAM", /, 32X, "A PRODUCT OF",VORT0640
     1        /, 23X, "OGIVE ENGINEERING (ASD/ENJEA)", //, 25X,           VORT0650
     2        "*** CONTROL CARD INPUT ***")                               VORT0660
      WRITE (6,102) IPROBE, ISCREEN, DELPR, DELVOR,                       VORT0670
     1               RIN, ROT, NOT, NORAKS, DELAN                         VORT0680
  102 FORMAT ( /, 9X, "IPROBE", 8X, "ISCREEN", 10X, "DELPR", 9X,          VORT0690
     1        "DELVOR", 12X, "RIN", /, 2I15, 3F15.2, //, 12X, "ROT",      VORT0700
     2        12X, "NOT", 9X, "NORAKS", 10X, "DELAN", /, F15.2, 2I15,     VORT0710
     3        F15.2 )                                                     VORT0720
      WRITE (6,115) PS2, TT2, AIRFLO, NPLOT1                              VORT0730
  115 FORMAT ( /, 12X, "PS2", 12X, "TT2", 9X, "AIRFLO", 9X,               VORT0740
     1        "NPLOT1", /, F15.4, F15.2, F15.3, I15 )                     VORT0750
      WRITE (6,103) (ANGLES(I),I=1,NORAKS)                                VORT0760
  103 FORMAT ( /, 9X, "ANGLES", /, (4F15.2) )                             VORT0770
      WRITE (6,104) ( RADII(I), I=1,NOT )                                 VORT0780
  104 FORMAT ( /, 9X, "RADII", /, (4F15.4) )                              VORT0790
      IF (IPROBE .NE. 0 ) WRITE (6,105) (IPROBS(I),I=1,IPROBE)            VORT0800
  105 FORMAT ( //, 9X, "DELETED PROBES", /, 10X, 12I5 )                   VORT0810
      ANGLES(NOA) = ANGLES(1) + 360.                                      VORT0820
      IF ( NPLOT1 .EQ. 2 ) GO TO 3                                        VORT0830
      XTIME = TIME                                                        VORT0840
    2 CALL SPREAD ( TIME, DATA )                                          VORT0850
      IF ( ( XTIME - .00002 ) .GE. TIME ) GO TO 2                         VORT0860
      IF ( ( XTIME + .00002 ) .LT. TIME ) GO TO 2                         VORT0870
      GO TO 5                                                             VORT0880
```

```
    3 TIME = TIME + 1.0                                                 VORT0890
C                                                                       VORT0900
C   PROCESS DATA TO ELIMINATE BAD PROBES                                VORT0910
C                                                                       VORT0920
    5 IF ( IPROBE .EQ. 0 ) GO TO 7                                      VORT0930
      DO 6 I=1,48                                                       VORT0940
      DO 6 J=1,IPROBE                                                   VORT0950
      IF ( IPROBS(I) .EQ. I ) DATA(I) = 0.0                             VORT0960
    6 CONTINUE                                                          VORT0970
      GO TO 8                                                           VORT0980
    7 IF ( ISCREEN .EQ. 0 ) GO TO 10                                    VORT0990
    8 CALL SCREEN ( DATA, NOA, NOT, I2, KFAILS )                        VORT1000
      IF ( KFAILS .EQ. 1 ) WRITE (6,107) TIME                           VORT1010
  107 FORMAT ( /, 5X, "A SCAN HAS FAILED SCREEN TEST AT TIME =", F20.5 )VORT1020
C                                                                       VORT1030
C   NORMALIZE AND PRINT DATA                                            VORT1040
C                                                                       VORT1050
   10 NUM = 0                                                           VORT1060
      NUMB=0                                                            VORT1070
      DO 13 I=1,NOA                                                     VORT1080
      DO 13 J=1,NOT                                                     VORT1090
      NUM = NUM + 1                                                     VORT1100
      IF (I.EQ.NOA ) GO TO 12                                           VORT1110
      PTOPR(I,J) = DATA(NUM)                                            VORT1120
      GO TO 13                                                          VORT1130
   12 NUMB=NUMB+1                                                       VORT1140
      PTOPR(I,J)=DATA(NUMB)                                             VORT1150
      RADII(J) = RADII(J) / ROT                                         VORT1160
   13 CONTINUE                                                          VORT1170
      IF ( ROT .EQ. 1. .AND. ISWITCH .EQ. 1 ) GO TO 14                  VORT1180
      ISWITCH = 1                                                       VORT1190
      AREA = ( ROT**2 - RIN**2 ) * 3.1415927                            VORT1200
      RIN = RIN / ROT                                                   VORT1210
      ROT1 = ROT                                                        VORT1220
      ROT = 1.0                                                         VORT1230
   14 CALL COMP(1)                                                      VORT1240
C                                                                       VORT1250
C   CALCULATE RADIAL VORTICITY                                          VORT1260
C                                                                       VORT1270
      DO 20 J=1,NOT                                                     VORT1280
      GRADTH(NOA,J) = GRADTH(1,J)                                       VORT1290
   20 CONTINUE                                                          VORT1300
      CALL MACH (XM, GAMMA, A)                                          VORT1310
      Q = APOPR-PS2                                                     VORT1320
```

```
      COEF = A / ( GAMMA * (ROT1/12.) * XM )
      DO 21 I=1,NOA
      DO 21 J=1,NOT
      GRADTH(I,J) = COEF / (PTOPB(I,J)*SQRT((PTOPR(I,J)-PS2)/Q))
     1               * GRADTH(I,J)
   21 CONTINUE
C
C  CALCULATE CIRCUMFERENTIAL VORTICITY
C
      DO 25 J=1,NOT
      GRADR(NOA,J) = GRADR(1,J)
   25 CONTINUE
      DO 26 I=1,NOA
      DO 26 J=1,NOT
      GRADR(I,J) = -COEF / (PTOPB(I,J)*SQRT((PTOPR(I,J)-PS2)/Q))
     1               * GRADR(I,J)
   26 CONTINUE
C
C  WRITE OUT VORTICITY VALUES
C
      WRITE (6,101) TITLE
      WRITE (6,108) TIME
  108 FORMAT ( /, 10X, "CASE NUMBER =", F10.5 )
      WRITE (6,110)
  110 FORMAT ( /, 1X, "*** RADIAL VORTICITY ***")
      WRITE (6,111) ( ANGLES(I),I=1,NORAKS)
  111 FORMAT ( /, 6X, "RAKE =", 8F14.1, //, 6X, "RD / OD")
      DO 27 J=1,NOT
      WRITE (6,113) RADII(J), ( GRADTH(I,J),I=1,NORAKS )
  113 FORMAT ( F11.5, 2X, 8F14.2 )
   27 CONTINUE
      WRITE (6,114)
  114 FORMAT ( //, 1X, "*** CIRCUMFERENTIAL VORTICITY ***")
      WRITE (6,111) (ANGLES(I),I=1,NORAKS)
      DO 28 J=1,NOT
      WRITE(6,113) RADII(J), (GRADR(I,J),I=1,NORAKS)
   28 CONTINUE
      DO 29 I=1,NORAKS
      DO 29 J=1,NOT
      PTOPR(I,J) = SQRT ( GRADR(I,J)**2 + GRADTH(I,J)**2 )
   29 CONTINUE
      WRITE (6,115)
      DO 31 J=1,NOT
      PTOPR(NOA,J) = PTOPR(1,J)
```

```
   31 CONTINUE                                                          VORT1770
  115 FORMAT ( //, 1X, "*** TOTAL VORTICITY ***" )                      VORT1780
      WRITE (6,111) (ANGLES(I),I=1,NORAKS )                             VORT1790
      DO 30 J=1,NOT                                                     VORT1800
      WRITE (6,113) RADII(J), (PTOPR(I,J),I=1,NORAKS)                   VORT1810
   30 CONTINUE                                                          VORT1820
C                                                                       VORT1830
C   PRINT OUT MAP OF TOTAL VORTICITY                                    VORT1840
C                                                                       VORT1850
      CALL COMP(2)                                                      VORT1860
      GO TO 1                                                           VORT1870
      END                                                               VORT1880
      SUBROUTINE BMFIT(L,N,X,Y,SLOPE0,SLOPEN,A,B,C,D)                   BMFI0010
      DIMENSION X(150), Y(150), A(150), B(150), C(150), D(150)          BMFI0020
      KN = 3*(L-L/3) - 2*L                                              BMFI0030
      K0 = (L-1)/3                                                      BMFI0040
      DO 1 J=2,N                                                        BMFI0050
      A(J) =  X(J)-X(J-1)                                               BMFI0060
    1 D(J) =  (Y(J)-Y(J-1))/A(J)                                        BMFI0070
      K2 =N-2                                                           BMFI0080
      IF (KN-1) 4,5,6                                                   BMFI0090
    4 C(N) = 3.0*(SLOPEN-D(N))/A(N)                                     BMFI0100
      B(N) = 0.5                                                        BMFI0110
      K3=N                                                              BMFI0120
      K1 = 1                                                            BMFI0130
      GO TO 8                                                           BMFI0140
    5 T = 2.0*(A(N)+A(N-1))                                             BMFI0150
      B(N)=SLOPEN                                                       BMFI0160
      GO TO 7                                                           BMFI0170
    6 T = 3.0*A(N)+A(N-1)+A(N-1)                                        BMFI0180
      SLOPEN = 0.0                                                      BMFI0190
    7 C(N-1) =  (6.0*(D(N)-D(N-1))-SLOPEN*A(N))/T                       BMFI0200
      B(N-1) =  A(N-1)/T                                                BMFI0210
      K3 = N-1                                                          BMFI0220
      K1 = 2                                                            BMFI0230
    8 DO 9  J =K1,K2                                                    BMFI0240
      K = N-J                                                           BMFI0250
      T = 2.0*(A(K)+A(K+1))-A(K+1)*B(K+1)                               BMFI0260
      B(K) = A(K)/T                                                     BMFI0270
    9 C(K) = (6.0*(D(K+1)-D(K))-A(K+1)*C(K+1))/T                        BMFI0280
      IF (K0-1) 12,13,11                                                BMFI0290
   11 B(1) =(6.0* (D(2)-SLOPE0)-C(2)*A(2))/(A(2)*(2.0-B(2)))            BMFI0300
      K1 = 2                                                            BMFI0310
      GO TO 15                                                          BMFI0320
```

```
   12 B(1) = SLOPE0                                                           BMFI0330
      B(2) = C(2)-B(2)*B(1)                                                   BMFI0340
      GO TO 14                                                                BMFI0350
   13 B(1) =  (6.0*(D(3)-D(2))-A(3)*C(3))/(3.0*A(2)+A(3)*(2.0-B(3)))          BMFI0360
      B(2) = B(1)                                                             BMFI0370
   14 K1 = 3                                                                  BMFI0380
   15 DO 16   J=K1,K3                                                         BMFI0390
   16 B(J) = C(J)-B(J)*B(J-1)                                                 BMFI0400
      IF (KN-1) 18,18,17                                                      BMFI0410
   17 B(N) = B(N-1)                                                           BMFI0420
C     CUBIC COEFFICIENTS                                                      BMFI0430
   18 DO 19 J=2,N                                                             BMFI0440
      TA = 6.0 * A(J)                                                         BMFI0450
      TM = B(J-1)*X(J)                                                        BMFI0460
      TN = X(J-1)*B(J)                                                        BMFI0470
      TX = X(J)*(X(J)-X(J-1)-X(J-1))                                          BMFI0480
      TY = X(J-1)*(X(J)+X(J)-X(J-1))                                          BMFI0490
      A(J-1) =  (B(J)-B(J-1))/TA                                              BMFI0500
      C(J-1)=D(J)+(B(J)*(-TX)+2.0*X(J-1)*TN-B(J-1)*TY-2.0*X(J)*TM)/TA         BMFI0510
      B(J-1) =  (TM-TN)*3.0/TA                                                BMFI0520
   19 D(J-1) =(TX*TN +TY*TM)/TA +Y(J-1)-X(J-1)*D(J)                           BMFI0530
      RETURN                                                                  BMFI0540
        END                                                                   BMFI0550
      SUBROUTINE BMVAL(NN, XINP, M, VALU, A2, B2, C2, D2, IO, Z, XDERV1)      BMVA0010
      DIMENSION                                                               BMVA0020
     1 A2     (10,15 ), B2     (10,15 ), C2     (10,15 ), D2     (10,15 ),    BMVA0030
     2 XINP   (100       )                                                    BMVA0040
      M = 0                                                                   BMVA0050
      DO 1 J=1,NN                                                             BMVA0060
      IF (XINP(J)-VALU) 1,3,3                                                 BMVA0070
    1 CONTINUE                                                                BMVA0080
C     OUT OF RANGE                                                            BMVA0090
      M= 1                                                                    BMVA0100
      J = NN                                                                  BMVA0110
      GO TO 4                                                                 BMVA0120
    3 IF (J-1) 5,5,4                                                          BMVA0130
    4 Z= VALU*(VALU*(VALJ*A2(J-1,IO)+B2(J-1,IO))+C2(J-1,IO))+D2(J-1,IO)       BMVA0140
      XDERV1 = VALU*(3.0*VALU*A2(J-1,IO) +2.0*B2(J-1,IO))+C2(J-1,IO)          BMVA0150
      RETURN                                                                  BMVA0160
    5 J=J+1                                                                   BMVA0170
      GO TO 4                                                                 BMVA0180
        END                                                                   BMVA0190
      SUBROUTINE CHECK ( I )                                                  CHEC0010
      GO TO ( 3, 3, 3, 4, 5, 6, 10, 10, 10, 10 ), I                           CHEC0020
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```
3     WRITE(6,301)                                                      CHEC0030
301   FORMAT(5X,51H JN INDEX OF PRES VARIABLE EXCEEDS 12              ) CHEC0040
      RETURN                                                            CHEC0050
4     WRITE(6,401)                                                      CHEC0060
401   FORMAT(5X,51H JO INDEX OF ANGFI VARIABLE EXCEEDS 120            ) CHEC0070
      RETURN                                                            CHEC0080
5     WRITE(6,501)                                                      CHEC0090
501   FORMAT(5X,51H JP INDEX OF ANG VARIABLE EXCEEDS 30               ) CHEC0100
      RETURN                                                            CHEC0110
6     WRITE(6,601)                                                      CHEC0120
601   FORMAT(5X,51H IN INDEX OF PRF1,RA,RADD AND YANG EXCEEDS 120     ) CHEC0130
      RETURN                                                            CHEC0140
  10  WRITE(6,1001)                                                     CHEC0150
1001  FORMAT(5X,51H TOTAL NUMBER OF POINTS IN PATTERN EXCEEDS 840     ) CHEC0160
      RETURN                                                            CHEC0170
         END                                                            CHEC0180
      SUBROUTINE COMP(ITEST)                                            COMP0010
      COMMON / SETUP1 / ANG(10), RAD(10), TITLE(8), TIME                COMP0020
      COMMON / SETUP2 / DELPR, RIN, ROT, NOT, NOA, DELAN, NORAKS, APOPR,COMP0030
     1                  DELVOR                                          COMP0040
      COMMON / SETUP5 / PTOPR(10,10), PTOPB(10,10), T2(10,10)           COMP0050
      DIMENSION AJOAT(10), AVGPHI(20), C(21), CC(21,10), PRAOPR(10),    COMP0060
     1 SUM(20), TOTPC(10), X(11), XC(21,11), Y(21,10), YY(21),          COMP0070
     2 PINGAV(10)                                                       COMP0080
      DATA YC, XC / 232*0.1 /                                           COMP0090
      DATA ISAVE / 0 /                                                  COMP0100
      DELR = (1.0 - RIN)/10.0                                           COMP0110
      NPHI = NOA                                                        COMP0120
      RADIAN= .017453292                                                COMP0130
      PI = 3.1415927                                                    COMP0140
      TWOPI = 2.0 * PI                                                  COMP0150
      DO 906 I = 1, NOA                                                 COMP0160
  906 X(I+1) = ANG(I) * RADIAN                                          COMP0170
      X(1) = X(NOA) - TWOPI                                             COMP0180
      X(NOA+2) = X(3) + TWOPI                                           COMP0190
      DO 907 J = 1, NOT                                                 COMP0200
      Y(1,J) = PTOPR ( NPHI-1, J)                                       COMP0210
      DO 908 I = 1, NPHI                                                COMP0220
      N=I+1                                                             COMP0230
  908 Y(N,J)=PTOPR(I,J)                                                 COMP0240
  907 Y( NPHI+2, J) = PTOPR(2,J)                                        COMP0250
      JFLAG = 0                                                         COMP0260
      JFLAG = 0                                                         COMP0270
      NPIP=NPHI+2                                                       COMP0280
```

```
      DO 909 J = 1, NOT                                                  COMP0290
      IFLAG = 0                                                          COMP0300
      KFLAG = 0                                                          COMP0310
      LL = 0                                                             COMP0320
      DO 910 I=1,NPIP                                                    COMP0330
  910 YY(I)=Y(I,J)                                                       COMP0340
      CALL SPL503 ( X, YY, NPIP, C )                                     COMP0350
      DO 911 I=1,NPIP                                                    COMP0360
  911 CC(I,J)=C(I)                                                       COMP0370
  905 IF (JFLAG .EQ. 0) GO TO 904                                        COMP0380
      YCI = YY(2)                                                        COMP0390
      DO 912 I=2,NPHI                                                    COMP0400
      H=X(I+1)-X(I)                                                      COMP0410
      DELTA=H/10.                                                        COMP0420
      XP=X(I)                                                            COMP0430
      IF (I .GT. 2 .OR. Y(I,J) .GE. PRAOPR(J)) GO TO 954                 COMP0440
      IFLAG = 1                                                          COMP0450
      ISAVE = 2                                                          COMP0460
      KFLAG = 1                                                          COMP0470
  954 DO 913 N = 2, 11                                                   COMP0480
      XC(I,N)=XP+DELTA                                                   COMP0490
      ETA=(XC(I,N)-X(I))/H                                               COMP0500
      PT1 =Y(I,J)+(Y(I+1,J)-Y(I,J))*ETA-CC(I,J)*(H**2)*(ETA-ETA**2)      COMP0510
      PT2 =H**2*(CC(I,J)-CC(I+1,J))*(3.*ETA**3 -5.*ETA**4+2.*ETA**5)     COMP0520
      YC = PT1 + PT2                                                     COMP0530
      IF ( IFLAG .EQ. 0 .AND. YC .GT. PRAOPR(J)  .OR.                    COMP0540
     1     IFLAG .EQ. 1 .AND. YC .LT. PRAOPR(J)      ) GO TO 955         COMP0550
      THETA1 = (PRAOPR(J)-YCI) / (YC-YCI) * (XC(I,N)-XP) + XP            COMP0560
      IF (IFLAG .EQ. 0 ) GO TO 956                                       COMP0570
  962 PRMIN = YY(ISAVE)                                                  COMP0580
      LIM = I + 1                                                        COMP0590
      DO 960 L = ISAVE,LIM                                               COMP0600
      IF (YY(L) .LT. PRMIN) PRMIN = YY(L)                                COMP0610
  960 CONTINUE                                                           COMP0620
      IF ( PRMIN .GE. PRAOPR(J)) GO TO 958                               COMP0630
      IF ( KFLAG .EQ. 0 .OR. ISAVE .NE. 2 ) GO TO 959                    COMP0640
      THETS = THETA1 - X(2)                                              COMP0650
      PRSAVE = PRMIN                                                     COMP0660
      CALL DIF25 ( THETA1, THETA2, X(2), KFLAG, J, THETS, LL, ITROLE )   COMP0670
      GO TO 958                                                          COMP0680
  956 ISAVE = I                                                          COMP0690
      THETA2 = THETA1                                                    COMP0700
      IFLAG = 1                                                          COMP0710
      GO TO 955                                                          COMP0720
```

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  959 IF (KFLAG .EQ. 1  .AND.  I .EQ. NPHI  .AND.  N .EQ. 11) GO TO 957 COMP0730
      CALL DIF25 ( THETA1, THETA2, X(2), KFLAG, J, THETS, LL, ITPOLE )  COMP0740
      IF ( ITPOLE .EQ. 1 )  GO TO  958                                  COMP0750
      GO TO 961                                                         COMP0760
  957 IF ( PRSAVE .LT. PRMIN ) PRMIN = PRSAVE                           COMP0770
      KFLAG = 0                                                         COMP0780
  961 LL = LL + 1                                                       COMP0790
  958 IFLAG = 0                                                         COMP0800
  955 IF (KFLAG .EQ. 1  .AND.  I .EQ. NPHI  .AND.  N .EQ. 11) GO TO 962 COMP0810
      YCI = YC                                                          COMP0820
      XP = XC(I,N)                                                      COMP0830
  913 CONTINUE                                                          COMP0840
  912 CONTINUE                                                          COMP0850
      IF (JFLAG .EQ. 1) JFLAG = 0                                       COMP0860
      GO TO 909                                                         COMP0870
  904 CONTINUE                                                          COMP0880
      DO 914 I = 1, NORAKS                                              COMP0890
  914 AVGPHI(I) = ( ANG(I+1) + ANG(I) ) / 2.0                           COMP0900
          SUM(J)=0.0                                                    COMP0910
          DO 9917 I=2,NPHI                                              COMP0920
      IF(I.NE.NPHI)GO TO 99917                                          COMP0930
      SUM(J)=SUM(J)+PTOPR(I,J)*(AVGPHI(1)+(360. -AVGPHI(NORAKS)))/360.  COMP0940
      GO TO 9917                                                        COMP0950
99917 SUM(J)=SUM(J)+PTOPR(I,J)*(AVGPHI(I)-AVGPHI(I-1))/360.             COMP0960
 9917 CONTINUE                                                          COMP0970
      PRAOPR(J)=SUM(J)                                                  COMP0980
      JFLAG=1                                                           COMP0990
      GO TO 905                                                         COMP1000
  909 CONTINUE                                                          COMP1010
      ATOTAL = ( 1.0 - RIN**2 ) * PI / 4.0                              COMP1020
      DO 922 J = 1, NOT                                                 COMP1030
      TOTPC(J) = ( RAD(J)**2 - RIN**2 ) * PI / ( 4.0 * ATOTAL )         COMP1040
      IF(TOTPC(J))923,922,922                                           COMP1050
  923 WRITE (6,925) J, RAD(J), RIN                                      COMP1060
  925 FORMAT(/1X11HAT RING NO.,I2,16H THE INPUT DIAM.,F8.4,22H IS LESS TCOMP1070
     1HAN ID DIAM.,F8.4/)                                               COMP1080
      GO TO 821                                                         COMP1090
  922 CONTINUE                                                          COMP1100
      AJOAT(1)=(TOTPC(1)+TOTPC(2))/2.                                   COMP1110
      K = NOT - 1                                                       COMP1120
      DO 930 J=2,K                                                      COMP1130
  930 AJOAT(J)=(TOTPC(J+1)-TOTPC(J-1))/2.                               COMP1140
      AJOAT(NOT) = 1.0 - ( TOTPC(NOT-1) + TOTPC(NOT) ) / 2.0            COMP1150
      APOPR=0.0                                                         COMP1160
```

```
      DO 931 J = 1, NOT                                                 COMP1170
  931 APOPR=APOPR+PRAOPR(J)*AJOAT(J)                                    COMP1180
      IF ( ITEST .EQ. 1 ) GO TO 933                                     COMP1190
      DO 932 I=1,NOA                                                    COMP1200
      DO 932 J=1,NOT                                                    COMP1210
      PTOP3(I,J) = PTOPR(I,J)                                           COMP1220
  932 CONTINUE                                                          COMP1230
      GO TO 821                                                         COMP1240
  933 DO 32 J=1,NOT                                                     COMP1250
      DO 32 I=1,NOA                                                     COMP1260
      PTOP3(I,J) = PTOPR(I,J)/APOPR                                     COMP1270
   32 CONTINUE                                                          COMP1280
      IF (ITEST.EQ.2) GO TO 821                                         COMP1290
C                                                                       COMP1300
C  CALCULATE RING AVERAGE PRESSURE                                      COMP1310
C                                                                       COMP1320
      DO 2 J=1,NOT                                                      COMP1330
      RINGAV(J) = 0.0                                                   COMP1340
      DO 1 I=1,NORAKS                                                   COMP1350
      RINGAV(J) = RINGAV(J) + PTOP3(I,J)                                COMP1360
    1 CONTINUE                                                          COMP1370
      RINGAV(J) = RINGAV(J) / FLOAT(NORAKS)                             COMP1380
    2 CONTINUE                                                          COMP1390
  821 CALL PREPAT ( DELR, IM, K, ITEST )                                COMP1400
      CALL PATERN(K, ITEST)                                             COMP1410
      RETURN                                                            COMP1420
      END                                                               COMP1430
      SUBROUTINE CONPUN ( JN, RADR, JQ, PRESS, ANGFI, 32, C2, D2, A2,   CONP0010
     1                    PRS, PRL, IM, K, ITEST )                      CONP0020
      COMMON             JSIM(840), PLABEL(36), XTEM(840), YTEM(840),   CONP0030
     1                   MAXSYM                                         CONP0040
      COMMON / SETUP2 / DELPR, RIN, ROT, NOT, NOA, DELAN, NORAKS, APOPR,CONP0050
     1                   DELVOR                                         CONP0060
      COMMON / SETUP5 / PTOPR(10,10), PTOP3(10,10), I2(10,10)           CONP0070
      DIMENSION ANGFI(1), B2(10,15), C2(10,15), D2(10,15), PRF1(120),   CONP0080
     1 A2(10,15), PRESS(120,12), PRP(12), RADD(120), RADR(1), YANG(120) CONP0090
      MAXSYM = 1                                                        CONP0100
      DO 5 IZ = 1, 840                                                  CONP0110
      XTEM(IZ)=0.0                                                      CONP0120
      YTEM(IZ)=0.0                                                      CONP0130
    5 JSIM(IZ)=0                                                        CONP0140
      ING = 0                                                           CONP0150
      NING= 1                                                           CONP0160
      K = 0                                                             CONP0170
```

```
      NNING = NING
      IF ( ITEST .EQ. 1 ) DEL = DELPR
      IF ( ITEST .EQ. 2 ) DEL = DELVOR
      DO 393 MX=1,JQ
      DO 32  J=1,JN
32    PRP(J) = PRESS(MX,J)
      CALL BMFIT (5,JN,RADR(1),PRP(1),0.0,0.0,A2(1,1),B2(1,1),C2(1,1),D2
     1(1,1))
      CALL FALPO ( PRP(1), IM, PRS, DEL, M, PRF1, 7, 32, TEST, D2,
     1            NOUNT, A2, C2, JN, PRL, RADD, RADR )
      IF ( IM .EQ. 0 )  GO TO 393
      IF ( IM .LE. 120 )  GO TO 34
      CALL CHECK (6 )
      GO TO 40
34    PRO = PRS
      ING = 0
      NING = NNING
      DO 392 J=1,IM
      K = K +1
      YANG(J) = RADD(J) * COS ( ANGFI(MX) * 0.0174533 )
      RADD(J) = RADD(J) * SIN ( ANGFI(MX) * 0.0174533 )
      IF ( TEST .NE. 0.0 )  GO TO 40
   35 IF ( PRO - PRF1(J) )  37, 39, 36
36    IF (PRF1(J)-1.0) 37,39,392
   37 PRO = PRO + DEL
      IF ( ING .GE. 9 )  GO TO 381
      ING = ING + 1
      GO TO 35
381   IF (ING-16) 382,383,384
382   ING = ING + 7
      GO TO 35
383   ING = ING + 16
      GO TO 35
384   ING = 0
      NING=NING + 1
      GO TO 35
   39 CALL OUTP ( NING, PRF1, K, ING, PLABEL, JSTM, MAXSYM, J )
      IF ( K .GT. 840 )  RETURN
      XTEM(K) = RADD(J)
      YTEM(K) = YANG(J)
392   CONTINUE
393   CONTINUE
   40 RETURN
        END
```

```
      SUBROUTINE DIF25 ( THETA1, THETA2. X2. KFLAG. NOA. THETS, LL,      DIF20010
     1 ITROLE )                                                          DIF20020
      DATA ISAVNO / 0 /                                                  DIF20030
      ITROLE = 0                                                         DIF20040
      IF ( NOA .EQ. ISAVNO )  GO TO 10                                   DIF20050
      SAVET1 = THETA1 + 0.4363323                                        DIF20060
      SAVET2 = THETA2                                                    DIF20070
      SAVEX2 = X2                                                        DIF20080
      ISAVFL = KFLAG                                                     DIF20090
      ISAVNO = NOA                                                       DIF20100
      RETURN                                                             DIF20110
   10 IF ( THETA2 .GT. SAVET1 )  RETURN                                  DIF20120
      LL = LL - 1                                                        DIF20130
      THETA2 = SAVET2                                                    DIF20140
      IF ( ISAVFL .EQ. 0 )  RETURN                                       DIF20150
      LL = LL + 1                                                        DIF20160
      ITROLE = 1                                                         DIF20170
      THETS = THETA1 - SAVEX2                                            DIF20180
      RETURN                                                             DIF20190
      END                                                                DIF20200
      SUBROUTINE FALPO(PRP.IM,PRS,DELPR,M,PRF1.Z.B2.TEST,D2.NOUNT.A2,C2.FALP0010
     1 JN,PRL,RADD,RADR)                                                 FALP0020
      DIMENSION                                                          FALP0030
     1 PRP    (12      ), PRF1 (120   ), RADD   (120   ), RADR   (12      ), FALP0040
     2 A2     (10,15 ), B2    (10,15), C2     (10,15), D2     (10,15    )  FALP0050
      IM =1                                                              FALP0060
      PRF1(IM) = PRS                                                     FALP0070
      NOUNT =0                                                           FALP0080
      JM= JN-1                                                           FALP0090
32    DO 29 JK=1,JM                                                      FALP0100
      NOUNT =0                                                           FALP0110
      IF  (PRP(JK)-PRF1(IM)) 25,27,28                                    FALP0120
25    IF  (PRP(JK+1)-PRF1(IM)) 29,29,26                                  FALP0130
28    IF  (PRP(JK+1)-PRF1(IM)) 26,29,29                                  FALP0140
26    RADLO    = RADR(JK)                                                FALP0150
      RADHI    = RADR(JK+1)                                              FALP0160
      PRELO    = PRP(JK)                                                 FALP0170
      PREHI    = PRP(JK+1)                                               FALP0180
5     VALU    =(RADHI+RADLO)/2.0                                         FALP0190
      CALL BMVAL (JN, RADR(1), M, VALU, A2(1,1), B2(1,1), C2(1,1),       FALP0200
     1            D2(1,1) , 1, 7, XDERV1)                                FALP0210
      IF (ABS(Z-PRF1(IM))-.0005) 7,7,530                                 FALP0220
80    IF  (Z- PRF1(IM)) 3,7,1                                            FALP0230
1     IF  (PRELO - PRF1(IM)) 2,4,9                                       FALP0240
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3     IF (PREHI - PRF1(IM)) 10,11,6                                     FALP0250
2     RADHI= VALU                                                       FALP0260
      PREHI= Z                                                          FALP0270
      GO TO 5                                                           FALP0280
6     RADLO = VALU                                                      FALP0290
      PRELO = Z                                                         FALP0300
      GO TO 5                                                           FALP0310
9     RADLO = RADHI                                                     FALP0320
      PRELO = PREHI                                                     FALP0330
      GO TO 2                                                           FALP0340
10    RADHI = RADLO                                                     FALP0350
      PREHI = PRELO                                                     FALP0360
      GO TO 6                                                           FALP0370
4     RADD(IM) = RADLO                                                  FALP0380
      GO TO 78                                                          FALP0390
11    RADD(IM) = RADHI                                                  FALP0400
      GO TO 78                                                          FALP0410
7     RADD(IM) = VALU                                                   FALP0420
78    PRF1(IM+1)= PRF1(IM)                                              FALP0430
      IM =IM+1                                                          FALP0440
      GO TO 29                                                          FALP0450
530   NOUNT = NOUNT+1                                                   FALP0460
      IF (NOUNT-50) 80,125,125                                          FALP0470
125   WRITE (6,9025)                                                    FALP0480
9025  FORMAT (32HONO CONVERGENCE IN 50 ITERATIONS )                     FALP0490
      GO TO 29                                                          FALP0500
27    RADD(IM) =RADP(JK)                                                FALP0510
      GO TO 78                                                          FALP0520
29    CONTINUE                                                          FALP0530
      IF (PRF1(IM)-PRL) 91,57,57                                        FALP0540
91    PRF1(IM)=PRF1(IM)+DELPR                                           FALP0550
      IF (PRF1(IM)-PRL) 32,32,82                                        FALP0560
82    PRF1(IM)=PRL                                                      FALP0570
      GO TO 32                                                          FALP0580
57    TEST =0.0                                                         FALP0590
      PRF1(IM)=0.0                                                      FALP0600
      IM=IM-1                                                           FALP0610
      RETURN                                                            FALP0620
        END                                                             FALP0630
      SUBROUTINE LISTER                                                 LIST0010
      DIMENSION C(20)                                                   LIST0020
      DATA KARD / 1 /                                                   LIST0030
      REWIND 5                                                          LIST0040
   30 WRITE(6,20)                                                       LIST0050
```

```
20 FORMAT ( "1", 2(/), 1X, 43("*"), " CARD INPUT ", 43("*") )          LIST0060
   WRITE(6,40)                                                           LIST0070
40 FORMAT(/                                                              LIST0080
  1 " CARD", T20, 10("1"), 10("2"), 10("3"), 10("4"), 10("5"),           LIST0090
  2 10("6"), 10("7"), "8", /, " COLUMN", T11, 8("1234567890"),5X,       LIST0100
  3 "CARD", / )                                                          LIST0110
   DO 25 J=1,50                                                          LIST0120
 1 READ (5,5) C                                                          LIST0130
   IF (EOF(5).NE.0.) GO TO 15                                            LIST0140
 5 FORMAT(20A4)                                                          LIST0150
   WRITE(6,10) C,KARD                                                    LIST0160
10 FORMAT( 10X, 20A4, I8 )                                               LIST0170
   KARD = KARD + 1                                                       LIST0180
25 CONTINUE                                                              LIST0190
   WRITE(6,40)                                                           LIST0200
   GO TO 30                                                              LIST0210
15 REWIND 5                                                              LIST0220
   WRITE(6,40)                                                           LIST0230
   RETURN                                                                LIST0240
   END                                                                   LIST0250
   SUBROUTINE MACH ( XM, GAMMA, A )                                      MACH0010
C                                                                        MACH0020
C  THIS SUBROUTINE CALCULATES ENGINE FACE MACH NUMBER, CP, AND GAMMA     MACH0030
C                                                                        MACH0040
   COMMON / SETUP4 / TT2, PS2, AREA, AIRFLO                              MACH0050
   G = 32.174                                                            MACH0060
   XM = 0.30                                                             MACH0070
   FP = AIRFLO * SQRT(518.69) / 14.697 / AREA                            MACH0080
   CP = 0.2318 + 0.1040E-04 * TT2 + 0.7166E-08 * TT2*TT2                 MACH0090
   R = 53.34                                                             MACH0100
   GAMMA = CP / ( CP - ( R / 778.3 ) )                                   MACH0110
   CON = SQRT ( GAMMA * G / R )                                          MACH0120
 5 X = SQRT ( 1.0 + ( GAMMA - 1.0 ) / 2.0 * XM * XM )                    MACH0130
   Y = ( 1.0 + (GAMMA-1.0)/2.0 * XM*XM) ** (GAMMA/(GAMMA-1.0))           MACH0140
   FPC = CON * XM * X / Y                                                MACH0150
   DEL = FP - FPC                                                        MACH0160
   IF ( ABS(DEL) .LE. 0.002 ) GO TO 12                                   MACH0170
   XM = FP / FPC * XM                                                    MACH0180
   GO TO 5                                                               MACH0190
12 A = SQRT ( TT2 * 1716. * GAMMA )                                      MACH0200
   RETURN                                                                MACH0210
   END                                                                   MACH0220
   SUBROUTINE OUTP ( NING, PRF1, K, ING, PLABEL, JSIM, MAXSYM, J )       OUTP0010
   DIMENSION JSIM(1), PLABEL(1), PRF1(1)                                 OUTP0020
```

```
      IF ( ING - 16 )  11, 12, 13                                       OUTP0030
11    ISYM = ING + 1   + (NING-1) * 12                                  OUTP0040
      GO TO 14                                                          OUTP0050
12    ISYM = 11        + (NING-1) * 12                                  OUTP0060
      GO TO 14                                                          OUTP0070
13    ISYM = 12        + (NING-1) * 12                                  OUTP0080
   14 IF ( ISYM .GT. 36 )   GO TO 50                                    OUTP0090
      PLABEL(ISYM)=PRF1(J)                                              OUTP0100
   50 JSIM (K)= ISYM                                                    OUTP0110
      IF ( ISYM .GT. MAXSYM ) MAXSYM =ISYM                              OUTP0120
      RETURN                                                            OUTP0130
        END                                                             OUTP0140
      SUBROUTINE PATERN (K,ITEST)                                       PATE0010
      COMMON              JSIM(840), PLABEL(36), XTEM(840), YTEM(840),  PATE0020
     1                    MAXSYM                                        PATE0030
      COMMON / SETUP1 / ANG(10), RAD(10),   RECORD(8), TIME             PATE0040
      COMMON / SETUP2 / DELPR, RIN, ROT, NOT, NOA, DELAN, NORAKS, APORR,PATE0050
     1                  DELVOR                                          PATE0060
      COMMON / SETUP4 / TT2, PS2, AREA, AIRFLO                          PATE0070
      INTEGER A                                                         PATE0080
      DIMENSION A(36), IRAY(1000),                                      PATE0090
     1           DUMMY(5), JRAY(95), TEMP(2,3), XIN(32), B(8),          PATE0100
     2            XOUT(94), XOUU(34), YIN(32), YOUT(94), YOUU(34),      PATE0110
     3           VORT(5,3), C(8)                                        PATE0120
      DATA A / 1H0, 1H1, 1H2, 1H3, 1H4, 1H5, 1H6,                       PATE0130
     1   1H7, 1H8, 1H9, 1HA, 1HB, 1HC, 1HD, 1HE, 1HF, 1HG, 1HH,         PATE0140
     2   1HI, 1HJ, 1HK, 1HL, 1HM, 1HN, 1HO, 1HP, 1HQ, 1HR, 1HS, 1HT,    PATE0150
     3   1HU, 1HV, 1HW, 1HX, 1HY, 1HZ   /                               PATE0160
      DATA B / 4HSYMB, 4HOL (, 4HLOOK, 4HING , 4HAFT), 4H PTL, 4H/PTL,  PATE0170
     1         4HAVG /                                                  PATE0180
      DATA C / 4HSYMB, 4HOL (, 4HLOOK, 4HING , 4HAFT), 4H VOR, 4HTICI,  PATE0190
     1         4HTY    /                                                PATE0200
      DATA JUTSIN/1H*/                                                  PATE0210
      DATA VORT / 4HAV.V, 4HTIME, 4HTT2-, 4HPS2-, 4HAIRF,               PATE0220
     1            4HORTI, 4H----, 4H----, 4H----, 4HLO--,               PATE0230
     2            4HCITY, 4H----, 4H----, 4H----, 4H---- /              PATE0240
      DATA TEMP / 4HA.WT, 4HTIME, 4H.AVG, 4H----, 4H.PR., 4H----/       PATE0250
      DATA IBLANK / 1H  /                                               PATE0260
      DATA    XIN /     0.0002,    -0.0002,     0.1396,    -0.1396,     PATE0270
     X    0.2066,    -0.2066,     0.2750,    -0.2750,     0.2944,       PATE0280
     X   -0.2944,     0.3142,    -0.3142,     0.3347,    -0.3347,       PATE0290
     X    0.3394,    -0.3394,     0.3394,    -0.3394,     0.3347,       PATE0300
     X   -0.3347,     0.3142,    -0.3142,     0.2944,    -0.2944,       PATE0310
     X    0.2750,    -0.2750,     0.2066,    -0.2066,     0.1396,       PATE0320
```

```
X    -0.1396,     -0.0002,     0.0002/                                          PATE0330
 DATA     YIN /     0.3400,      0.3400,      0.3100,      0.3100,              PATE0340
X     0.2700,      0.2700,     0.2000,     0.2000,     0.1700,                  PATE0350
X     0.1700,      0.1300,     0.1300,     0.0600,     0.0600,                  PATE0360
X     0.0200,      0.0200,    -0.0200,    -0.0200,    -0.0600,                  PATE0370
X    -0.0600,     -0.1300,    -0.1300,    -0.1700,    -0.1700,                  PATE0380
X    -0.2000,     -0.2000,    -0.2700,    -0.2700,    -0.3100,                  PATE0390
X    -0.3100,     -0.3400,    -0.3400/                                          PATE0400
 DATA    XOUT /     0.0    ,     0.2800,     -0.2800,      0.3919,              PATE0410
X    -0.3919,      0.4750,    -0.4750,     0.5103,    -0.5103,                  PATE0420
X     0.5724,     -0.5724,     0.6258,    -0.6258,     0.6499,                  PATE0430
X    -0.6499,      0.6940,    -0.6940,     0.7332,    -0.7332,                  PATE0440
X     0.7684,     -0.7684,     0.7846,    -0.7846,     0.8000,                  PATE0450
X    -0.8000,      0.8146,    -0.8146,     0.8285,    -0.8285,                  PATE0460
X     0.8417,     -0.8417,     0.8660,    -0.8660,     0.8773,                  PATE0470
X    -0.8773,      0.8879,    -0.8879,     0.8980,    -0.8980,                  PATE0480
X     0.9165,     -0.9165,     0.9330,    -0.9330,     0.9474,                  PATE0490
X    -0.9474,      0.9539,    -0.9539,     0.9656,    -0.9656,                  PATE0500
X     0.9708,     -0.9708,     0.9755,    -0.9755,     0.9837,                  PATE0510
X    -0.9837,      0.9871,    -0.9871,     0.9950,    -0.9950,                  PATE0520
X     0.9982,     -0.9982,     0.9998,    -0.9998,     1.0000,                  PATE0530
X    -1.0000,      0.9998,    -0.9998,     0.9982,    -0.9982,                  PATE0540
X     0.9950,     -0.9950,     0.9871,    -0.9871,     0.9837,                  PATE0550
X    -0.9837,      0.9755,    -0.9755,     0.9708,    -0.9708,                  PATE0560
X     0.9656,     -0.9656,     0.9539,    -0.9539,     0.9474,                  PATE0570
X    -0.9474,      0.9330,    -0.9330,     0.9165,    -0.9165,                  PATE0580
X     0.8980,     -0.8980,     0.8879,    -0.8879,     0.8773/                  PATE0590
 DATA    XOUU /    -0.8773,      0.8660,     -0.8660,      0.8417,              PATE0600
X    -0.8417,      0.8285,    -0.8285,     0.8146,    -0.8146,                  PATE0610
X     0.8000,     -0.8000,     0.7846,    -0.7846,     0.7684,                  PATE0620
X    -0.7684,      0.7332,    -0.7332,     0.6940,    -0.6940,                  PATE0630
X     0.6499,     -0.6499,     0.6258,    -0.6258,     0.5724,                  PATE0640
X    -0.5724,      0.5103,    -0.5103,     0.4750,    -0.4750,                  PATE0650
X     0.3919,     -0.3919,     0.2800,    -0.2800,     0.0    /                 PATE0660
 DATA    YOUT /     1.0000,      0.9600,      0.9600,      0.9200,              PATE0670
X     0.9200,      0.8800,     0.8800,     0.8600,     0.8600,                  PATE0680
X     0.8200,      0.8200,     0.7800,     0.7800,     0.7600,                  PATE0690
X     0.7600,      0.7200,     0.7200,     0.6800,     0.6800,                  PATE0700
X     0.6400,      0.6400,     0.6200,     0.6200,     0.6000,                  PATE0710
X     0.6000,      0.5800,     0.5800,     0.5600,     0.5600,                  PATE0720
X     0.5400,      0.5400,     0.5000,     0.5000,     0.4800,                  PATE0730
X     0.4800,      0.4600,     0.4600,     0.4400,     0.4400,                  PATE0740
X     0.4000,      0.4000,     0.3600,     0.3600,     0.3200,                  PATE0750
X     0.3200,      0.3000,     0.3000,     0.2600,     0.2600,                  PATE0760
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     X      0.2400,      0.2400,      0.2200,      0.2200,      0.1800,          PATE0770
     X      0.1800,      0.1600,      0.1600,      0.1000,      0.1000,          PATE0780
     X      0.0600,      0.0600,      0.0200,      0.0200,     -0.0    ,         PATE0790
     X     -0.0   ,     -0.0200,     -0.0200,     -0.0600,     -0.0600,          PATE0800
     X     -0.1000,     -0.1000,     -0.1600,     -0.1600,     -0.1800,          PATE0810
     X     -0.1800,     -0.2200,     -0.2200,     -0.2400,     -0.2400,          PATE0820
     X     -0.2600,     -0.2600,     -0.3000,     -0.3000,     -0.3200,          PATE0830
     X     -0.3200,     -0.3600,     -0.3600,     -0.4000,     -0.4000,          PATE0840
     X     -0.4400,     -0.4400,     -0.4600,     -0.4600,     -0.4800/          PATE0850
      DATA   YOUU /     -0.4800,     -0.5000,     -0.5000,     -0.5400,        PATE0860
     X     -0.5400,     -0.5600,     -0.5600,     -0.5800,     -0.5800,          PATE0870
     X     -0.6000,     -0.6000,     -0.6200,     -0.6200,     -0.6400,          PATE0880
     X     -0.6400,     -0.6800,     -0.6800,     -0.7200,     -0.7200,          PATE0890
     X     -0.7600,     -0.7600,     -0.7800,     -0.7800,     -0.8200,          PATE0900
     X     -0.8200,     -0.8600,     -0.8600,     -0.8800,     -0.8800,          PATE0910
     X     -0.9200,     -0.9200,     -0.9600,     -0.9600,     -1.0000/          PATE0920
      DUMMY(1) = APOPR                                                          PATE0930
      DUMMY(2) = TIME                                                           PATE0940
      DUMMY(3) = TT2                                                            PATE0950
      DUMMY(4) = PS2                                                            PATE0960
      DUMMY(5) = AIRFLO                                                         PATE0970
      LADD = 0                                                                  PATE0980
      IF ( ITEST .EQ. 2 ) LADD = 3                                              PATE0990
      DO 330 I=1,1000                                                           PATE1000
  330 IRAY(I)=0                                                                 PATE1010
      DO 331 J=1,95                                                             PATE1020
  331 JRAY(J) = IBLANK                                                          PATE1030
      DO 6  IX = 1, K                                                           PATE1040
      IA = JSIM ( IX )                                                          PATE1050
      JSIM ( IX ) = A ( IA )                                                    PATE1060
    6 CONTINUE                                                                  PATE1070
      KI  = K                                                                   PATE1080
      DO 1 I = 1, 32                                                            PATE1090
      YTEM(I +KI) = YIN(I)                                                      PATE1100
      XTEM(I +KI) = XIN(I)                                                      PATE1110
      JSIM(I+KI)=JUTSIN                                                         PATE1120
1     CONTINUE                                                                  PATE1130
      KI = KI + 32                                                              PATE1140
      DO 2  J = 1, 94                                                           PATE1150
      YTEM(J + KI) = YOUT (J)                                                   PATE1160
      XTEM(J + KI) = XOUT (J)                                                   PATE1170
      JSIM(J+KI)=JUTSIN                                                         PATE1180
2     CONTINUE                                                                  PATE1190
      KI = KI + 94                                                              PATE1200
```

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      DO 3 J = 1, 34                                                    PATE1210
      YTEM ( J + KI ) = YOUU ( J )                                      PATE1220
      XTEM ( J + KI ) = XOUU ( J )                                      PATE1230
      JSIM(J+KI)=JUTSIN                                                 PATE1240
3     CONTINUE                                                          PATE1250
      KI = KI + 34                                                      PATE1260
      JTOT = KI + NOT * NORAKS                                          PATE1270
      CALL SORT1 ( JSIM   , YTEM, XTEM, JTOT   )                        PATE1280
      DO 30 J = 1, JTOT                                                 PATE1290
      IRAY(J) = IFIX(YTEM(J) * 28. + SIGN (.5, YTEM(J))) + 29           PATE1300
30    CONTINUE                                                          PATE1310
      WRITE (6,35) RECORD                                               PATE1320
   35 FORMAT (*1*11X,8A10,//)                                           PATE1330
      DO  40  K1= 1, 95                                                 PATE1340
      JRAY(K1)= IBLANK                                                  PATE1350
40    CONTINUE                                                          PATE1360
      DO 45  K1= 1, JTOT                                                PATE1370
45    IRAY (K1)=  58- IRAY ( K1)                                        PATE1380
      LINES = 1                                                         PATE1390
      JIP = 1                                                           PATE1400
   50 IF ( IRAY(JIP) .GT. LINES )  GO TO 70                             PATE1410
      ITEMP = IFIX ( XTEM(JIP) * 47.0 + SIGN ( 0.5, XTEM(JIP) )) + 48   PATE1420
      JRAY(ITEMP) = JSIM(JIP)                                           PATE1430
       IF ( JIP .EQ. JTOT ) GO TO 70                                    PATE1440
      JIP = JIP + 1                                                     PATE1450
      GO TO 50                                                          PATE1460
   70 IF ( LINES .GT. (2+LADD) ) GO TO 77                               PATE1470
      IF ( ITEST .EQ. 2 ) GO TO 71                                      PATE1480
      IF (LINES.EQ.1.AND.ITEST.EQ.2) GO TO 71                           PATE1490
      WRITE (6,201)  JRAY, ( TEMP(LINES,J),J=1,3 ), DUMMY(LINES)        PATE1500
  201 FORMAT(1X,95A1,6X,3A4,F14.5)                                      PATE1510
      GO TO 78                                                          PATE1520
   71 WRITE(6,201) JRAY, (VORT(LINES,J),J=1,3), DUMMY(LINES)            PATE1530
      GO TO 78                                                          PATE1540
   77 IF ( LINES .EQ. 29 ) JRAY(48) = JUTSIN                            PATE1550
      IF ( LINES .GT. (MAXSYM+4+LADD) ) GO TO 74                        PATE1560
      IF ( LINES .EQ. (LADD+3) ) GO TO 74                               PATE1570
      IF ( LINES .EQ. (LADD+4) ) GO TO 75                               PATE1580
      WRITE (6,795) JRAY, A(LINES-4-LADD), PLABEL(LINES-4-LADD)         PATE1590
  795 FORMAT ( 1X, 95A1, 11X, A2, 9X, F10.5 )                           PATE1600
      GO TO 78                                                          PATE1610
   74 WRITE (6,800)  JRAY                                               PATE1620
  800 FORMAT(1X,95A1)                                                   PATE1630
      GO TO 78                                                          PATE1640
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   75 IF ( ITEST .EQ. 2 ) GO TO 76
      WRITE (6,796) JRAY, B
      GO TO 78
   76 WRITE (6,796) JRAY, C
  796 FORMAT(1X,95A1,3X,8A4)
   78 LINES = LINES + 1
      DO 80 K2 = 1, 95
   80 JRAY(K2) = IBLANK
      IF ( LINES .LT. 58 )  GO TO 50
      RETURN
        END
      SUBROUTINE PREPAT (DELR,IM,K,ITEST)
      COMMON / SETUP1 / ANG(10), RAD(10), TITLE(8), TIME
      COMMON / SETUP2 / DELPR, RIN, ROT, NOT, NOA, DELAN, NORAKS, APOPR,
     1                  DELVOR
      COMMON / SETUP3 / GRADR(10,10), GRADTH(10,10)
      COMMON / SETUP5 / PTOPR(10,10), PTOPB(10,10), T2(10,10)
      DIMENSION A(10), A2(10,15), ANGFI(120), B2(10,15), C2(10,15),
     1          D(10), D2(10,15), PRES(15,12), PRP(12), Q(10), RADP(10),
     2          S(10), XPRSAV(15,3), PRESS(120,12)
C
C   CALCULATE THE MAX AND MIN NORMALIZED PRESSURES
C
      DELTH = DELAN / 360. * 2.0 * 3.1415927
      PRL = PTOPB(1,1)
      PRS  = PRL
      DO 6100 I=1,NOA
      DO 5901 J=1,NOT
      IF ( PTOPB(I,J) .GT. PRL )  PRL = PTOPB(I,J)
      IF ( PTOPB(I,J) .LT. PRS )  PRS = PTOPB(I,J)
 5901 CONTINUE
 6100 CONTINUE
      DISMAX = PRL - PRS
      DISBAR = 1.0 - PRS
      IF (ITEST.EQ.2) GO TO 6200
      CALL PRINT ( PRS, PRL, DISMAX, DISBAR)
 6200 PRST = 1.0
 6300 PRST = PRST-DELPR
      IF (PRST-PRS) 6400,6500,6300
 6400 PRS  = PRST+ DELPR
 6500 KNOT1 = 0
C
C   CALCULATE INTERPOLATED PRESSURES FOR PATTERN USING POLYNOMIAL
C      CURVE FIT
```

```
C
      IF ( NOT .NE. 3 )  GO TO 6550
      KNOT1 = 1
      DO 6520 I=1,NOA
      XPRSAV(I,3) = PTOPB(I,3)
      PTOPB(I,5) = PTOPB(I,3)
      XPRSAV(I,2) = PTOPB(I,2)
      PTOPB(I,3) = PTOPB(I,2)
      PTOPB(I,4) = ( PTOPB(I,5) + PTOPB(I,3) ) / 2.0
 6520 PTOPB(I,2) = ( PTOPB(I,3) + PTOPB(I,1) ) / 2.0
      XPRSA3 = RAD(3)
      XPRSA2 = RAD(2)
      RAD(5) = RAD(3)
      RAD(3) = RAD(2)
      RAD(4) = ( RAD(5) + RAD(3) ) / 2.0
      RAD(2) = ( RAD(1) + RAD(3) ) / 2.0
      NOT = 5
 6550 CONTINUE
      DO 6800 I=1,NOA
      DO 6600 J=1,NOT
 6600 PRP(J) = PTOPB(I,J)
      CALL BMFIT (5,NOT,RAD(1),PRP(1),0.0,0.0,A(1),Q(1),S(1),D(1))
      DO 6700 JK=1,NOT
      A2(JK,I) =A(JK)
      C2(JK,I) =S(JK)
      B2(JK,I) =Q(JK)
 6700 D2(JK,I) = D(JK)
 6800 CONTINUE
      IF (ITEST.EQ.2) GO TO 6901
C
C   CALCULATE RADIAL PRESSURE GRADIENTS
C
      DO 6900 I=1,NOA
      DO 6900 J=1,NOT
      CALL BMVAL (NOT, RAD(1), M, RAD(J), A2(1,1), B2(1,1), C2(1,1),
     1            D2(1,1), I, 7, XDERV1)
      GRADR(I,J) = XDERV1
 6900 CONTINUE
 6901 RADR(1) = RAD(1)
      JN = 1
      GO TO 7200
 7000 JN =JN+1
      IF (JN     .LE. 12    ) GO TO 7010
      CALL CHECK ( 3  )
```

```
      RETURN
 7010 RADR(JN) = RADR(JN-1)+DELR
      IF ( RADR(JN) .LE. RAD(NOT) )   GO TO 7200
      RADR(JN) = RAD(NOT)
 7200 DO 7300 J=1,NOA
      VALU = RADR(JN)
      CALL BMVAL (NOT, RAD(1), M, VALU, A2(1,1), B2(1,1), C2(1,1),
     1            D2(1,1), J, Z, XDERV1)
      PRES(J,JN) = Z
 7300 CONTINUE
      IF ( RADR(JN) .LT. RAD(NOT) )   GO TO 7000
      NA = 0
      ANGFI(1) = ANG(1)
      JP = 1
      JQ = 1
      GO TO 7350
 7340 JQ  = JQ+1
      IF (JQ     .LE. 120   ) GO TO 7345
      CALL CHECK ( 4   )
      RETURN
 7345 ANGFI(JQ) = ANGFI(JQ-1) +DELAN
 7350 IF (ANGFI(JQ)-ANG(NOA)) 7370,7370,7360
 7360 ANGFI(JQ)=ANG(NOA)
 7370 IF (ANGFI(JQ)-ANG(JP)) 7400,7390,7380
 7380 JP = JP+1
      IF   (JP-NOA) 7370,7370,7400
 7390 NA = 1
      GO TO 7410
 7400 NA = 0
      IF (JP     .LE. 15    ) GO TO 7405
      CALL CHECK ( 5   )
      RETURN
 7405 PERC = (ANGFI(JQ)- ANG(JP-1)) /(ANG(JP)-ANG(JP-1))
 7410 DO 7440  JZ=1,JN
      IF (NA) 7430,7420,7430
 7420 PRESS (JQ,JZ) = (PRES(JP,JZ) -PRES(JP-1,JZ)) * PERC+ PRES(JP-1,JZ)
      GO TO 7440
 7430 PRESS(JQ,JZ) = PRES(JP,JZ)
 7440 CONTINUE
      IF ( ANGFI(JQ) .LT. ANG(NOA) )   GO TO 7340
      CALL CONPUN ( JN, RADR, JQ, PRESS, ANGFI, B2, C2, D2, A2, PRS,
     1              PRL, IM, K, ITEST )
      IF ( KNOT1 .EQ. 0 )   GO TO 7460
      NOT = 3
```

```
      RAD(3) = XPPSA3
      RAD(2) = XPPSA2
      DO 7451 I=1,NOA
      PTOP3(I,2) = XPPSAV(I,2)
 7451 PTOP3(I,3) = XPRSAV(I,3)
      IF (ITEST.EQ.2) GO TO 9000
C
C  CALCULATE CIRCUMFERENTIAL PRESSURE GRADIENTS
C
 7460 IANG = 0
      IFI = 0
 8000 IANG = IANG + 1
 8001 IFI = IFI + 1
      IF ( ANG(IANG) - ANGFI(IFI) ) 8010, 8002, 8001
 8002 IF ( IFI.EQ.1 ) GO TO 8010
      ISKIP = 2
      IFIP1 = IFI + 1
      SKIP = 2.0
      IFIM1 = IFI - 1
 8003 DO 8006 I=IFIM1, IFIP1, ISKIP
      DO 8004 J=1,JN
      PRP(J) = PRESS(I,J)
 8004 CONTINUE
      CALL RMFIT (5,JN,RADR(1),PRP(1),0.0,0.0,A2(1,1),B2(1,1),C2(1,1),D2
     1(1,1))
      DO 8005 J=1,NOT
      CALL RMVAL (JN, RADR(1), M, RAD(J), A2(1,1), B2(1,1), C2(1,1),
     1            D2(1,1), 1, Z, XDERV1)
      PRESS(I,J) = Z
 8006 CONTINUE
      DO 8007 J=1,NOT
      GRADTH(IANG,J) = (PRESS(IFIP1,J)-PRESS(IFIM1,J)) / (SKIP*DELTH*
     1                 RAD(J))
 8007 CONTINUE
      IF ( IANG .LT. NOPAKS) GO TO 8000
      GO TO 9000
 8010 IFIP1 = IFI + 1
      IFIM1 = IFI
      ISKIP = 1
      SKIP = 1.0
      GO TO 8003
 9000 RETURN
      END
      SUBROUTINE PRINT ( XPS, XPL, DISMAX, DISBAR)
```

```
      COMMON / SETUP1 / ANG(10), RAD(10), RECORD(8), TIME                PRIN0020
      COMMON / SETUP2 / DELPR, RIN, ROT, NOT, NOA, DELAN, NORAKS, APOPP,PRIN0030
     1                  DELVOP                                           PRIN0040
      COMMON / SETUP5 / PTOPR(10,10), PTOPB(10,10), T2(10,10)            PRIN0050
      PRS=XPS                                                            PRIN0060
      PRL=XPL                                                            PRIN0070
      DSMAX=DISMAX                                                       PRIN0080
      DSBAR=DISBAR                                                       PRIN0090
      WRITE (6,100)  RECORD                                              PRIN0100
  100 FORMAT ( 1H1, 5X, 8A10 )                                           PRIN0110
      WRITE (6,101)  TIME                                                PRIN0120
  101 FORMAT ( / 10X, "CASE NUMBER = ", F12.5 )                          PRIN0130
      WRITE (6,102) RIN, NOT, NORAKS                                     PRIN0140
  102 FORMAT ( / 10X, "INNER RADIUS / OUTER RADIUS = ", F7.5, 15X,       PRIN0150
     1 "NO. OF PROBES PER RAKE = ", I1, 15X, "NO. OF RAKES = ", I1 )     PRIN0160
      WRITE (6,103)  ANG(1), ANG(2), ANG(3), ANG(4)                      PRIN0170
  103 FORMAT ( // 22X, "RAKE = ", F5.1, 15X, "RAKE = ", F5.1, 15X,       PRIN0180
     1 "RAKE = ", F5.1, 15X, "RAKE = ", F5.1 )                           PRIN0190
      WRITE (6,104)                                                      PRIN0200
  104 FORMAT ( / 6X, "RD/OD", 11X, "PTL", 6X, "PTL/PTLAVG", 8X, "PTL",   PRIN0210
     1 6X, "PTL/PTLAVG", 8X, "PTL", 6X, "PTL/PTLAVG", 8X, "PTL", 6X,     PRIN0220
     2 "PTL/PTLAVG" )                                                    PRIN0230
      WRITE (6,105)   ( RAD(J), PTOPR(1,J), I2(1,J), PTOPB(1,J),         PRIN0240
     1 PTOPR(2,J), I2(2,J), PTOPB(2,J), PTOPR(3,J), I2(3,J), PTOPB(3,J),PRIN0250
     2 PTOPR(4,J), I2(4,J), PTOPB(4,J), J = 1, NOT )                     PRIN0260
  105 FORMAT ( 5X, F7.5, 7X, F8.5, A1, 4X, F7.5, 7X, F8.5, A1, 4X, F7.5,PRIN0270
     1               7X, F8.5, A1, 4X, F7.5, 7X, F8.5, A1, 4X, F7.5)PRIN0280
      WRITE (6,103)  ANG(5), ANG(6), ANG(7), ANG(8)                      PRIN0290
      WRITE (6,104)                                                      PRIN0300
      WRITE (6,105)   ( RAD(J), PTOPR(5,J), I2(5,J), PTOPB(5,J),         PRIN0310
     1 PTOPR(6,J), I2(6,J), PTOPB(6,J), PTOPR(7,J), I2(7,J), PTOPB(7,J),PRIN0320
     2 PTOPR(8,J), I2(8,J), PTOPB(8,J), J = 1, NOT )                     PRIN0330
      WRITE (6,111)  APOPP, PRS, DSMAX, PRL, DSBAR                       PRIN0340
  111 FORMAT ( // 5X, "AREA WEIGHTED PRESSURE AVERAGE = ", F8.5, 4X,     PRIN0350
     1 "PTL/PTLAVG MINIMUM = ", F8.5, 4X, "DISTORTION (MAX-MIN)/AVG = ",PRIN0360
     2 F6.4, / 50X, "PTL/PTLAVG MAXIMUM = ", F8.5, 4X,                   PRIN0370
     3 "DISTORTION (AVG-MIN)/AVG = ", F6.4 )                             PRIN0380
      RETURN                                                             PRIN0390
      END                                                                PRIN0400
      SUBROUTINE SCREEN ( DAI,  NR, NPR, IFLAG, KFAILS )                 SCRE0010
      DIMENSION DAI(1), IFLAG(10,10), IGOOD(10,10), IFLUG(100)           SCRE0020
      DATA IPLUS, ISTAR, IBLNK, IMINUS / 1H+, 1H*, 1H , 1H- /            SCRE0030
      ICYCLE = 0                                                         SCRE0040
      DO 2 I = 1,NR                                                      SCRE0050
```

```
      DO 2 J = 1,NPR                                                    SCRE0060
      IGOOD(I,J) = 0                                                    SCRE0070
      K = I * NPR + J - NPR                                             SCRE0080
      IF(DAI(K).EQ.0.0) IGOOD(I,J) = 2                                  SCRE0090
    2 CONTINUE                                                          SCRE0100
      KFAILS=0                                                          SCRE0110
      MNL=1                                                             SCRE0120
   10 AVE=0                                                             SCRE0130
      CNT=0                                                             SCRE0140
      DO 9 I=1,NR                                                       SCRE0150
      DO 9 J=1,NPR                                                      SCRE0160
      IF (IGOOD(I,J).GE.1) GO TO 9                                      SCRE0170
      K = I * NPR + J - NPR                                             SCRE0180
      AVE=AVE+DAI(K)                                                    SCRE0190
      CNT=CNT+1                                                         SCRE0200
    9 CONTINUE                                                          SCRE0210
      AVE=AVE/CNT                                                       SCRE0220
      SIGMA=0                                                           SCRE0230
      DO 11 I=1,NR                                                      SCRE0240
      DO 11 J=1,NPR                                                     SCRE0250
      IF (IGOOD(I,J).GE.1) GO TO 11                                     SCRE0260
      K = I * NPR + J - NPR                                             SCRE0270
      SIGMA=SIGMA+(DAI(K)-AVE)**2                                       SCRE0280
   11 CONTINUE                                                          SCRE0290
      SIGMA=SQRT(SIGMA/(CNT-1.))     * 4.                               SCRE0300
      DEL=0                                                             SCRE0310
      M=0                                                               SCRE0320
      N=0                                                               SCRE0330
      IF ( MNL .EQ. 2 ) GO TO 15                                        SCRE0340
      MNL = 2                                                           SCRE0350
      TAV=AVE                                                           SCRE0360
   15 DO 12 I=1,NR                                                      SCRE0370
      DO 12 J=1,NPR                                                     SCRE0380
      IF (IGOOD(I,J).GE.1) GO TO 12                                     SCRE0390
      K = I * NPR + J - NPR                                             SCRE0400
      DELL=ABS(AVE-DAI(K))                                              SCRE0410
      IF (DELL.LE.    SIGMA) GO TO 12                                   SCRE0420
      IF (DELL.LT.DEL) GO TO 12                                         SCRE0430
      DEL=DELL                                                          SCRE0440
      M=I                                                               SCRE0450
      N=J                                                               SCRE0460
   12 CONTINUE                                                          SCRE0470
      IF (M.EQ.0) GO TO 13                                              SCRE0480
      IGOOD(M,N)=1                                                      SCRE0490
```

```
      GO TO 10
   13 DO 16 I=1,NR
      DO 16 J=1,NPR
      IF (IGOOD(I,J).NE.1) GO TO 16
      K = I * NPR + J - NPR
      IF (ABS(1.-DAI(K)/TAV) .GE.0.1) IGOOD(I,J)=2
   16 CONTINUE
   20 DO 17 I = 1, NR
      DO 17 J=1,NPR
      SUM=0
      COUNT=0
      K = I * NPR + J - NPR
      L = J * 10  + I - 10
      IFLAG(L) = IBLNK
      IF (IGOOD(I,J).LT.1) GO TO 17
      IFLAG(L) = ISTAR
      IF (J.EQ.1)   GO TO 18
      IF (J.EQ.NPR) GO TO 18
      IF (IGOOD(I,J-1).NE.0) GO TO 18
      IF (IGOOD(I,J+1).NE.0) GO TO 18
      SUM=SUM+(DAI(K-1)+DAI(K+1))/2.
      COUNT=1
   18 N=I-I/NR*NR+1
      M=I+NR-2-(I+NR-2)/NR*NR+1
      IF (IGOOD(N,J).NE.0) GO TO 19
      IF (IGOOD(M,J).NE.0) GO TO 19
      N = N * NPR + J - NPR
      M = M * NPR + J - NPR
      SUM=SUM+(DAI(N)+DAI(M))/2.
      COUNT=COUNT+1
   19 IF (COUNT.EQ.0.) COUNT=1.
      DAI(K)=SUM/COUNT
      IF ( DAI(K) .EQ. 0.0 )  IFLAG(L) = IPLUS
      IF ( DAI(K) .EQ. 0.0 .AND. J .EQ. 1 )  DAI(K) = DAI(K+1)
      IF ( DAI(K) .EQ. 0.0 .AND. J .EQ. NPR )  DAI(K) = DAI(K-1)
      IF(DAI(K).EQ.0.0) KFAILS=1
      IF ( DAI(K) .NE. 0.0 )  IGOOD(I,J) = 0
   17 CONTINUE
      IF ( KFAILS .EQ. 0 .OR. ICYCLE .EQ. 1 )  GO TO 99
      KFAILS = 0
      ICYCLE = 1
      DO 22 I = 1, 50
   22 IFLUG(I) = IFLAG(I)
      GO TO 20
```

```
99 IF ( ICYCLE .EQ. 0 )   RETURN                                       SCREF0940
   DO 23 I = 1, 50                                                       SCREF0950
   IF ( IFLAG(I) .NE. IBLNK )   IFLUG(I) = IMINUS                        SCREF0960
23 IFLAG(I) = IFLUG(I)                                                   SCREF0970
   RETURN                                                                SCREF0980
   END                                                                   SCREF0990
   SUBROUTINE SORT1 ( JS  , X,  Y, JTOT  )                               SORT0010
   DIMENSION JS ( 1), X (1), Y ( 1)                                      SORT0020
   IMAX = JTOT - 1                                                       SORT0030
   DO 2 I = 1, IMAX                                                      SORT0040
   IP1 = I + 1                                                           SORT0050
   DO 2 J = IP1, JTOT                                                    SORT0060
   IF (X(I) - X(J))     3,2,2                                            SORT0070
3  T = X (J )                                                            SORT0080
   X ( J) = X ( I )                                                      SORT0090
   X ( I ) = T                                                           SORT0100
   T = Y ( J )                                                           SORT0110
   Y ( J ) = Y ( I )                                                     SORT0120
   Y ( I ) = T                                                           SORT0130
   L = JS ( J )                                                          SORT0140
   JS ( J ) = JS ( I )                                                   SORT0150
   JS ( I ) = L                                                          SORT0160
2  CONTINUE                                                              SORT0170
   RETURN                                                                SORT0180
     END                                                                 SORT0190
   SUBROUTINE SPL5D3 ( X, Y, N, C )                                      SPL50010
   DIMENSION X(1), Y(1), C(1)                                            SPL50020
   I = 2                                                                 SPL50030
   H            = X(2) - X(1)                                            SPL50040
   GO TO 20                                                              SPL50050
10 H            = FK                                                     SPL50060
20 FK           = X(I+1)  - X(I)                                         SPL50070
   ZE           = - H/FK                                                 SPL50080
   C(I) = (( 1.0 - ZE ) * Y(I) + ZE * Y(I+1) - Y(I-1) ) / ( FK * FK *SPL50090
  1 ZE * ( 1.0 - ZE ) )                                                  SPL50100
   I = I + 1                                                             SPL50110
   IF ( I .LT. N )   GO TO 10                                            SPL50120
   C(I) = 0.0                                                            SPL50130
   C(1) = 0.0                                                            SPL50140
   RETURN                                                                SPL50150
     END                                                                 SPL50160
   SUBROUTINE SPREAD ( TIME, DATA )                                      SPREF0010
   DIMENSION DATA(1)                                                     SPREF0020
C                                                                        SPREF0030
```

```
C   THIS SPACE IS ALLOCATED FOR A TAPE READING ROUTINE                   SPRE0040
C                                                                        SPRE0050
      RETURN                                                             SPRE0060
      END                                                                SPRE0070
```

```
*********************************************** CARD INPUT ***********************************************

CARD              1111111111222222222233333333334444444444555555555566666666667777777777 8         CARD
COLUMN   12345678901234567890123456789012345678901234567890123456789012345678901234567890

         $DATIN TITLE(1)=1, TT2=590, PS2=2.7206, AIRFLO=200.20,                                  1
         DATA(1) = 3.10010, 3.11407, 3.15956, 3.12406, 3.11376, 3.11780,                         2
                   3.13402, 3.32462, 3.30073, 3.29071, 3.16272, 3.11418,                         3
                   3.39525, 3.21221, 3.37151, 3.21165, 3.24471, 3.25520,                         4
                   3.10447, 3.46745, 3.61    , 3.66589, 3.51330, 3.30069,                        5
                   3.09674, 3.77151, 3.67845, 3.63970, 3.41631, 3.41795,                         6
                   3.11472, 3.23727, 3.60012, 3.65233, 3.62314, 3.47165,                         7
                   3.10423, 3.17716, 3.42652, 3.24037, 3.24004, 3.21895,                         8
                   3.11944, 3.13539, 3.14776, 3.24113, 3.24534, 3.25177 $                        9
         H1-13 DATA POINT 24 STEADY STATE                                                        10

CARD              1111111111222222222233333333334444444444555555555566666666667777777777 8         CARD
COLUMN   12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

MA-13 DATA POINT 24 STEADY STATE

. VORTICITY MAP PROGRAM
A PRODUCT OF
OGIV. ENGINEERING (ASD/ENJEA)

*** CONTROL CARD INPUT ***

IPRINT	ISCREEN	DELPP	DELVOR	RIN
0	0	.04	400.00	5.65
ROT	NOT	NDRAKS	DELAN	
17.39	6	3	5.00	
PS2	TT2	AIRFLO	NPLOT1	
2.7216	560.00	200.200	2	
ANGLES				
0.00	45.00	90.00	135.00	
180.00	225.00	270.00	315.00	
RADII				
7.2770	9.9190	11.9920	13.7560	
15.3100	16.7560			

HA-1[illegible] DATA POINT 24 STEADY STATE

CASE NUMBER = 1.00000

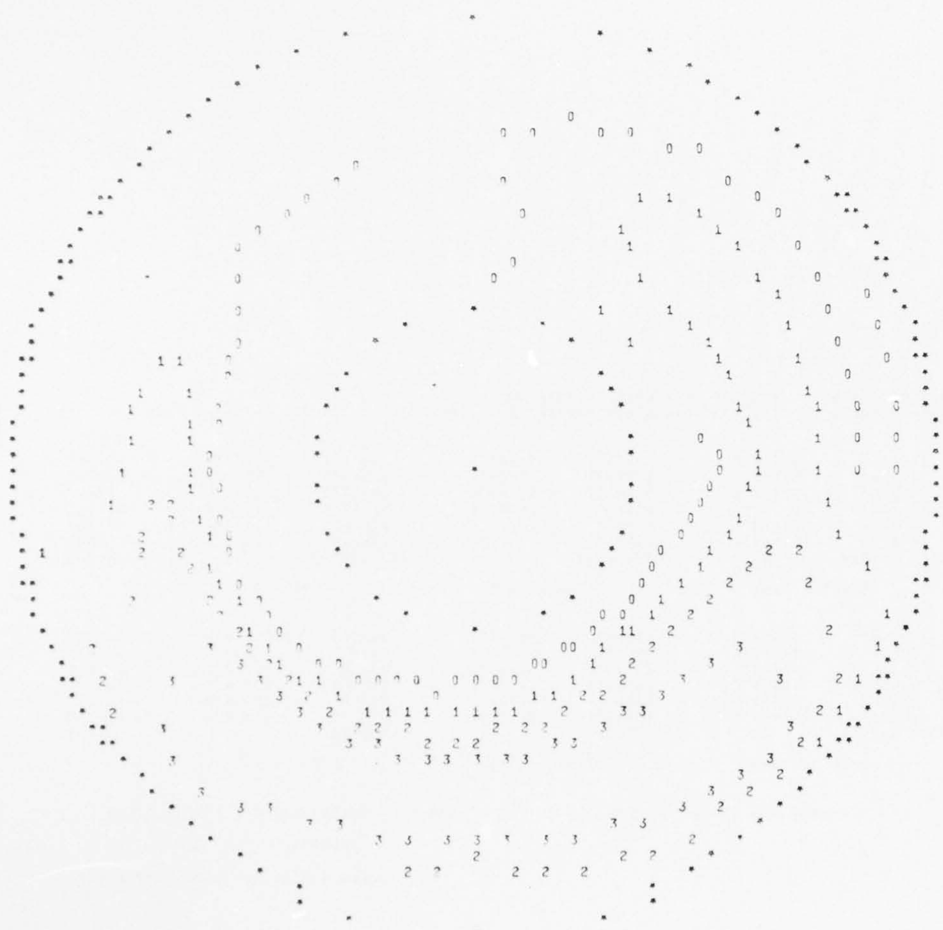
INNER RADIUS / OUTER RADIUS = .32496 NO. OF PROBES PER RAKE = 6 NO. OF RAKES = 8

	RAKE = 0.0		RAKE = 45.0		RAKE = 90.0		RAKE = 135.0	
R/RO	PTL	PTL/PTLAVG	PTL	PTL/PTLAVG	PTL	PTL/PTLAVG	PTL	PTL/PTLAVG
.41[illegible]	3.1[illegible]916	.9[illegible]	3.35452	1.01033	3.09629	.93373	3.10443	.94120
.57043	3.11507	.94442	3.32369	1.00913	3.21221	.97337	3.45745	1.05732
.69871	3.[illegible]	.95690	3.36073	1.02496	3.37151	1.02217	3.61000	1.09447
.79117	3.124[illegible]	.94715	3.25971	.98527	3.21165	.97370	3.65533	1.11175
.88106	3.11375	.9[illegible]	3.15272	.95584	3.14471	.95341	3.61330	1.09547
.96256	3.11780	.9[illegible]25	3.11413	.94415	3.25520	.96591	3.30069	1.00070

	RAKE = 180.0		RAKE = 225.0		RAKE = 270.0		RAKE = 315.0	
R/RO	PTL	PTL/PTLAVG	PTL	PTL/PTLAVG	PTL	PTL/PTLAVG	PTL	PTL/PTLAVG
.41[illegible]	3.[illegible]	.9[illegible]	3.10472	.94128	3.10429	.94115	3.11391	.94539
.57043	3.37151	1.02217	3.23227	.97935	3.17716	.96325	3.15539	.95658
.68871	3.[illegible]	1.11535	3.60012	1.09148	3.42652	1.03885	3.14775	.95434
.79117	3.[illegible]71	1.10227	3.65233	1.10745	3.24037	.98241	3.24113	.98264
.88106	3.41631	1.03575	3.62318	1.09847	3.24004	.98231	3.24554	.98407
.96256	3.41796	1.03625	3.47155	1.05253	3.21896	.97592	3.25177	.98587

AREA WEIGHTED PRESSURE AVERAGE = 3.29839 PTL/PTLAVG MINIMUM = .93373 DISTORTION (MAX-MIN)/AVG = .1766
PTL/PTLAVG MAXIMUM = 1.11535 DISTORTION (AVG-MIN)/AVG = .0613

MA-11 DATA POINT 24 STEADY STATE



A.WT.AVG.PR.	3.29639
TIME----------	1.00000

SYMBOL (LOOKING AFT)	PTL/PTLAVG
0	.96000
1	1.00000
2	1.04000
3	1.08000

HA-13 DATA POINT 24 STEADY STATE

CASE NUMBER = 1.00000

*** RADIAL VORTICITY ***

RAKE =	0.0	45.0	90.0	135.0	180.0	225.0	270.0	315.0
RO / OD								
.41853	272.12	-31.39	-184.70	.36	.23	5.97	12.03	35.42
.57049	244.22	42.07	78.41	58.24	-104.31	-93.62	-51.03	-34.97
.68971	199.53	72.54	77.89	83.43	-2.54	-69.09	-145.17	-121.53
.79117	110.14	29.93	145.35	94.67	-2.98	-88.11	-143.58	-42.13
.89106	28.93	10.90	162.55	57.76	2.50	-37.47	-116.63	-38.51
.96256	-2.44	46.57	51.89	42.87	39.66	-43.79	-64.07	-28.26

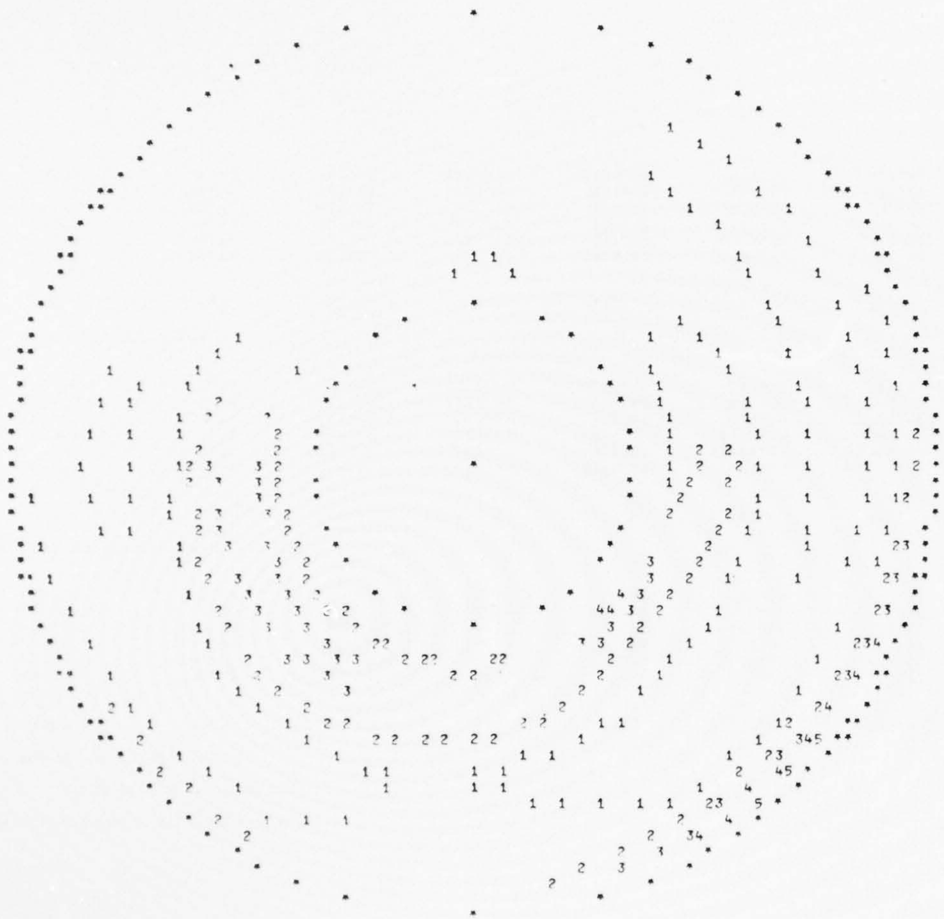
*** CIRCUMFERENTIAL VORTICITY ***

RAKE =	0.0	45.0	90.0	135.0	180.0	225.0	270.0	315.0
RO / OD								
.41853	371.73	262.09	124.07	-1814.22	-431.64	621.43	792.25	-158.29
.57049	-156.06	-233.73	-782.73	-510.08	-1029.61	-1244.10	-1156.89	53.53
.68971	1.71	146.08	109.18	-214.14	-378.64	-567.40	89.54	-336.90
.79117	158.14	613.55	763.53	-31.11	609.65	26.67	567.01	-237.40
.89106	-4.00	408.69	-154.05	535.48	586.63	276.16	-141.86	43.49
.96256	-46.66	51.12	-1007.96	2245.04	-599.85	921.42	373.69	-104.64

*** TOTAL VORTICITY ***

RAKE =	0.0	45.0	90.0	135.0	180.0	225.0	270.0	315.0
RO / OD								
.41853	460.72	263.95	222.50	1814.22	431.64	621.46	792.34	162.20
.57049	299.32	237.49	786.65	513.39	1034.88	1247.62	1158.02	63.94
.68971	199.59	165.70	134.11	229.32	378.65	571.59	170.56	358.15
.79117	192.72	614.28	777.36	124.67	609.66	92.05	584.90	241.11
.89106	29.21	408.83	223.96	539.27	586.63	278.69	183.65	58.08
.96256	46.73	59.15	1009.29	2245.45	601.16	922.46	379.14	108.39

HA-18 DATA POINT 24 STEADY STATE



AV.VORTICITY	484.29389
TIME--------	1.00000
TT2---------	590.00000
PS2---------	2.72060
AIRFLO------	200.20000

SYMBOL (LOOKING AFT)	VORTICITY
0	.35000
1	401.00000
2	801.00000
3	1201.00000
4	1601.00000
5	2001.00000

Appendix B

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AERONAUTICAL SYSTEMS DIVISION (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO
ATTN OF: YFEJ (Mr. Kanouse/53043) 20 APR 1976

SUBJECT: Distortion Report

TO: ASD/ENFPA (S. Clark)

YFEJ has reviewed the subject report and have determined it to be classified properly and have no objection to its publication.

CHARLES D. CULLOM, JR.
Chief, Propulsion & Power Division
Deputy for F-15/JEPO

1 Atch
Distortion Report

☆ U. S. GOVERNMENT PRINTING OFFICE: 1977 — 757-001/398